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FODDER CROPS FOR FATTENING LAMBS IN SEASONS OF LOW RAINFALL

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Summary

Four grazing experiments are described in which the ability of several fodder crops to fatten weaner lambs was compared. In view of the liveweight gains of the animals, and the productivity of the crops, it is concluded that, of the crops investigated, rape was the most useful.

The effects of two sowing rates, and of an application of nitrogenous fertilizer were also noted, but the overriding factor which limited the growth of all crops was the lack of moisture.

The general usefulness of fodder crops for grazing in dry, hot periods of the year is discussed, and it is concluded that they are of more value in periods of higher rainfall and lower temperatures.

ONE of the difficulties of raising fat lambs on non-irrigated farms in Victoria, where the spring growing season is relatively short, is that of finishing those lambs which are not fit for sale at weaning. It is the practice in southern Victoria to lamb in winter and to wean at the end of the spring. Under these conditions the possible solutions to this problem include the feeding of silage or a concentrate ration, or the grazing of a summer fodder crop. No work which measures the absolute or relative efficiencies of these different methods or determines the respective merits of various fodder crops has so far been reported.

This paper describes a series of experimental observations on the growth of various fodder crops, and of the lambs grazing them, which were made during the summers of 1957/8 and 1958/9. The experiments were carried out on the property of Mr. G. J. R. Coles, 'Kewarra', Mornington, Victoria, where eighteen plots, each one-third of an acre in area, were situated on a grey sandy loam in a locality with an annual average rainfall of 30 inches.

Plan of 1957/8 Experiments

The plots were grouped into three blocks of six, and six crops, rape, chou moellier, millet, and York globe, green globe, and purple-top turnips, were then randomly allocated to plots within each block. The complete area was mould-board ploughed in September 1957 and after a wet October was disced, and sown with the crops on 13 November 1957. Table 1 gives the sowing rates per acre. All the plots received 180 lb./acre of superphosphate.

Immediately after sowing, the plots were rolled, and 5 days later 1·61 inches of rain fell. This was followed by a period without effective rain which lasted until 25 December 1957 when a further 1·40 inches were recorded. Another period without rain followed and grazing began on

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10 January 1958. This first period of grazing ended on 17 February 1958 when the lambs were slaughtered. During this period of grazing no rain was recorded. However, 2 days after the lambs were removed 1·25 inches fell within 48 hours and after this considerable regrowth occurred on every plot. A second period of grazing was thus made possible, and this began on 22 March 1958 and lasted for 51 days. During the first period all the crops were grazed at the rate of twelve lambs per acre and during the second at the rate of nine lambs per acre.

TABLE 1. *Sowing Rates of Crops, 1957/8 and 1958/9*

Crop	*Sowing rate (lb./acre)*		
		1958/9	
	1957/8	*Expt. 1*	*Expt. 2*
Dwarf Essex rape . .	4	2 and 4	2
N.Z. green globe turnips .	2	1 and 2	..
N.Z. York globe turnips .	2	..	..
N.Z. purple-top turnips .	2	1 and 2	..
Japanese millet . .	12	..	..
Chou moellier . .	4	2 and 4	2
Kale	..	2 and 4	..
N.Z. Borre sweet lupins .	..	90 and 180	90

The lambs used in the first period were bred from Merino × Border Leicester ewes crossed with a Hampshire ram, and were weaned on 9 January 1958 when five months of age. The 72 lambs used were selected from a flock of 300 on the basis of sex and liveweight uniformity. They were then divided into sets of six on the basis of ascending liveweight and the individuals of each set were allocated at random to the six different crops. In this way the initial mean weights and weight ranges of the groups were similar. Each lamb was drenched with ¾ oz. of fine-particle phenothiazine before grazing commenced. Two lambs of the same breeding and one Border Leicester × Merino lamb were used in each plot in the second period of grazing and were selected and randomly allocated to groups in the same manner as before.

Plan of 1958/9 Experiments

The original intention was to compare six crops—rape, chou moellier, kale, green globe turnips, purple-top turnips, and N.Z. Borre sweet lupin—each replicated three times. However, red-legged earth mite and cutworms seriously attacked some of the replicates of all crops, except the lupins, when in the seedling stage and forced the abandonment of nine of the plots.

Therefore in Experiment 1 there were only nine plots, three containing Borre sweet lupins, two rape, and one each chou moellier, kale, green globe turnips, and purple-top turnips. The area had been mould-board ploughed in 1958 and after another wet October was disced and sown with the crops on 19 November 1958. One-half of each plot was sown at double the rate of the other half. Table 1 gives the sowing rates per acre. All plots received superphosphate at 180 lb./acre at sowing time

and on 4 December 1958 one-half of each sowing-rate subplot was top dressed with ammonium sulphate at 120 lb./acre. Immediately after sowing, the plots were rolled and 5 days later there was 0·72 in. of rain. Between 30 November and 13 December a further 2·48 in. were recorded, but after that no effective rain fell until 14 February. Grazing began on 16 January 1959 and ended when the animals were slaughtered on 4 March. The lambs used were bred from Merino × Border Leicester ewes crossed with a Dorset ram, and were weaned on 12 January when 4½ months of age. They were selected from a large flock and randomly allocated to treatments in the manner previously described. All plots were grazed at the rate of twelve lambs to the acre.

The nine abandoned plots were resown and used in Experiment 2, three being sown to rape, three to chou moellier, and three to Borre sweet lupins. Table 1 gives the sowing rates per acre. The crops were sown on 15 December and no effective rainfall fell between then and 14 February when 0·70 in. was recorded. During the first week of March 2·57 inches of rain were recorded. Grazing, at the rates of twelve lambs to the acre, began in all plots on 10 February and lasted until the animals were slaughtered on 1 April. The lambs were bred from Merino × Border Leicester ewes crossed with either a Southdown or Ryeland ram, and had been weaned on 12 January when 4½ months of age. They were selected and randomly allocated to treatments in the manner already described.

Methods

Before all periods of grazing in both years, the yields of each crop were estimated by cutting, in each plot, five random square-yard samples in the 1957/8 and eight in the 1958/9 season. The yields obtained were recorded and approximately one-tenth of each square-yard sample was taken for dry-weight determination. Also a count of the number of plants per square yard was made on the same sample areas before the initial grazings took place. Immediately after all grazing periods the residual yields of each crop were estimated by repeating this procedure.

The lambs were yarded for 16 hours before the initial and final weighings for each grazing period. At slaughter the carcass weight and grade of each lamb were recorded.

Results

The 1957/8 Season

The 1957/8 yields of dry matter per acre for each crop, before and after each period of grazing, together with the plant establishment records, are shown in Table 2. The mean initial and final weights of the lambs on each crop during each period of grazing in 1957/8, together with the carcass weights, are shown in Table 3. Average rainfall figures for the months October to April and those of 1957/8 and 1958/9 seasons are shown in Table 4. The results reflect the ability of the various crops to withstand dry conditions. From various reports based upon general observations, rape might have been expected to suffer most from the dry conditions, as it is often claimed to be less drought-resistant and more

susceptible to insect and fungus attack in a dry season than other fodder crops. In fact, however, rape proved to be as good an initial yielder as the other crops and because more remained after the first grazing period it was more persistent and vigorous in its regrowth.

TABLE 2. *Plant Establishment Records and Yields of Dry Matter Before and After Grazing, 1957/8*

Crop	No. of seeds/ acre ('000)	No. of plants/ acre ('000)	Plant survival (%)	Dry weight (lb./acre)			
				First grazing		Second grazing	
				Before*	After†	Before‡	After
Rape	400	198	50	2,403	861	1,727	1,044
Green globe turnip	500	126	25	2,537	345	685	none
York globe turnip	460	126	27	2,043	244	708	none
Purple-top turnip	340	82	24	2,567	684	1,193	none
Millet	1,392	252	18	1,900	151	753	none
Chou moellier	380	189	50	2,223	600	1,400	542

* Difference required for significance = 480 ($P < 0.05$).
† " " " " = 200 ($P < 0.05$).
‡ " " " " = 230 ($P < 0.05$).

TABLE 3. *Lamb Liveweight and Carcass Records for Each Period of Grazing, 1957/8*

Crop	Mean liveweight and liveweight gain of lambs (lb.)						Mean carcass weight (lb.)	
	First grazing			Second grazing			First grazing	Second grazing
	Before	After	Gain*	Before	After	Gain		
Rape	59	71	12	61	74	13	36	38
Green globe turnip	59	68	9	62	79†	17†	34	35†
York globe turnip	59	70	11	62	78	16‡	35	36‡
Purple-top turnip	59	67	8	63	76‡	13‡	34	36‡
Millet	59	69	10	62	§	§	32	§
Chou moellier	59	67	8	62	75	13	32	37

* A difference of 3 lb. needed for significance ($P < 0.05$).
† One replicate only lasted the grazing period.
‡ Two replicates only lasted the grazing period.
§ No replicate lasted the full grazing period.

TABLE 4. *Average Rainfall Figures for October to April*

Year	Rainfall (inches)						
	Oct.	Nov.	Dec.	Jan.	Feb.	March	April
1957/8	3·58	2·47	1·96	0·62	1·64	0·92	0·74
1958/9	5·04	2·61	2·09	0·40	1·30	3·20	0·99
Average (58 years)	2·65	2·23	2·07	1·84	1·43	2·05	2·49

Green globe and purple-top turnips gave significantly higher production than did York globe turnips and millet. Rape gave significantly higher production than millet. Other differences in production were not significant. At the end of the first grazing period rape, purple-top

turnips, and chou moellier gave significantly greater residues than the other crops and rape gave a residue that was significantly greater than that of chou moellier.

All crops showed a remarkable ability to recover from hard grazing, but regrowth did not occur when the 'growing points' of the plants had been destroyed.

Aphis were observed in the rape crops, but in small numbers only, and they did not interfere with the experiment.

In relating crop yields to animal production, a distinction must be made between the first and second grazings. During the first grazing period all the plots were stocked at the rate of twelve lambs per acre.

The only differences between the liveweights of lambs shown in Table 3 that reached significance are as follows. The lambs grazing rape gained more weight than did those grazing purple-top turnips and chou moellier. Those grazing York globe turnips also gained more weight than did those grazing purple-top turnips and chou moellier. The other differences were not significant.

With the crop yields that were obtained the stocking rate chosen was not high enough to produce the maximum difference in lamb production between crops. However, the crop-residue differences reflect the ability of the various fodders to maintain higher stocking rates. For example, at the end of the first grazing period almost all the crop on the three millet plots had been consumed, but there was plenty of fodder remaining on each of the rape plots. For this reason the rate of stocking used in the second grazing period was adjusted to a figure that was calculated to show up the varying abilities of the crops to give a high production of fat lamb. On the basis of how much rape was present, and of how efficient it had been in the first grazing in converting crop dry matter into animal liveweight gain, it was calculated that the rape regrowth would provide sufficient nutrients to fatten at least nine lambs to the acre. Similarly, it was calculated that it was improbable that the various turnips and the millet could do the same.

Table 3 illustrates the result of this second grazing, which lasted for 51 days. When all three lambs in any given plot lost weight over a period of at least one week the crop in that plot was considered to have been completely eliminated and supplementary feeding with hay was commenced. Those animals which had received supplementary feeding were not included when calculating the mean liveweight gains.

During the 51 days of grazing all three of the millet plots were eaten out, while two of the green globe turnip plots and one each of the purple-top and York globe turnip plots were also eliminated. The remaining turnip plots, although not completely eaten out in the sense that all animals were losing weight, were grazed to the extent that all vegetation above ground-level was removed and some of the animals had begun to lose weight. Consequently, when estimating the residues of dry matter per acre after this second grazing, all the turnip and millet replicates registered as zero.

Rape and chou moellier were the only two crops which persisted to the end of this second grazing. Rape in particular looked as though it could

have carried at least another four lambs to the acre, and calculations based on the final figure support this. Except for one replicate, most of the chou moellier had been stripped of its leaves and if grazing had been continued the stalks, too, would have soon been eaten.

Palatability Observations

Although no critical measurements were made, careful note was taken of the differences in palatability of the respective crops. This was made possible by including in the experimental layout a 12-acre area adjacent to the plots which was sown with all six fodder crops as continuations of the plot strips. Thus each fodder crop was replicated three times at random in the same manner as the crops in the plots, the only difference being that no fences existed between the strips. Nineteen lambs per acre grazed the area and had unrestricted access to all of the six varieties. In addition, they had access to small areas of New Zealand red globe turnips and hungry-gap and thousand-headed kale. It was noticeable that the lambs concentrated exclusively on all the millet strips until they were eaten bare. Grazing then became more widespread and preferences became less marked. The strips of York globe, green globe, and red globe turnips were the next to be eliminated and there was apparently little difference in the palatability of these crops, but the purple-top turnips appeared to be slightly less palatable. Rape and hungry-gap kale were the crops to disappear next, followed a little later by chou moellier. Thousand-headed kale proved to be markedly unpalatable and the lambs failed to eat it while a vestige of anything else remained.

The 1958/9 Season

The 1958/9 yields of dry matter per acre for each crop, before and after each experiment, together with the plant establishment records, are shown in Table 5. The mean initial and final weights of the lambs on each crop during each experiment in 1958/9, together with the carcass weights, are shown in Table 6. The responses of the crops in Experiment 1 to the application of the nitrogenous fertilizer are shown in Table 7.

The average rainfall figures in Table 4 show that the months of January and February 1959 were again considerably drier than the 58 years' average for these months. Also the 2·09 inches which fell during December 1958 occurred before 13 December. There was, therefore, a prolonged period of dry, hot weather which started at the time of sowing Experiment 2 and lasted almost until the end of the grazing period in Experiment 1.

Experiment 1. The yields of the crops were all extremely low, there being only approximately one-quarter of the dry matter per acre of the previous year. Because of the lack of replication in some of the treatments it was impossible to calculate the statistical significance of differences in yield. However, the Borre sweet lupin and rape crops were uniform, and comparatively high in production, while the chou moellier, kale, and green globe turnip crops were patchy and low in production.

Plant survival was low in all the crops. Halving the seeding rate reduced the plant number by about half, except with chou moellier.

TABLE 5. *Plant Establishment Records and Yields of Dry Matter Before and After Grazing, 1958/9*

(*a* = high sowing rate; *b* = low sowing rate)

Expt.	*Crop*	*No. of seeds/acre ('000)*		*No. of plants/acre ('000)*		*Plant survival %*		*Dry weight (lb.)/acre*		
								Before grazing		*After grazing*
		a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	
1	Rape	400	200	65	42	16	21	840	604	163
	Green globe turnip	500	250	78	30	16	12	549	341	none
	Purple-top turnip	340	170	63	42	19	25	748	590	none
	Chou moellier	380	190	78	81	21	43	521	621	none
	Kale	375	187	85	47	23	25	435	414	none
	Borre sweet lupins	530	265	207	117	39	44	1,198	1,036	none
2	Rape	400		143		36		729		748
	Chou moellier	380		138		37		683		676
	Borre sweet lupins	530		85		16		529		none

TABLE 6. *Lamb Liveweight and Carcass Records for Each Experiment, 1958/9*

Expt.	*Crop*	*Mean liveweight (lb.)*		*Mean liveweight gain (lb.)*	*Mean carcass weight (lb.)*
		Before grazing	*After grazing*		
1	Rape	67	70	3	35
	Green globe turnip	68	70	2	32
	Purple-top turnip	67	76	9*	36*
	Chou moellier	68	72	4	34
	Kale	67	69	2	33
	Sweet lupin	67	70	3	34
2	Rape	66	78	12	43
	Chou moellier	66	71	5	38
	Sweet lupin	66	69	3	35

* The lambs grazing purple-top turnips put on weight during hay feeding after the crop had been eaten out.

TABLE 7. *Response of Crop Yields to Nitrogenous Fertilizer, 1958/9*

Crop	*Yield (lb./acre)*		*% increase due to N*
	N	*No* N	
Rape	779	655	19
Green globe turnip	487	404	21
Purple-top turnip	679	659	3
Chou moellier	610	539	13
Kale	434	415	5
Sweet lupin	966	1,035	−7

The liveweight gain from the lambs grazing the crops was uniformly low (Table 6) and in all cases, except for those on rape, hay had to be fed after four or five weeks because the crops had been entirely eaten out.

The animals grazing purple-top turnips did not put on much weight until hay was offered and they then made much better weight gains than the others.

Experiment 2. Plant survival, especially with the sweet lupins, and the yields of the crops, were again low. However, the rain which fell in late February (0·98 inches) and in early March (2·50 inches) stimulated growth in the rape and chou moellier crops so much that their rates of growth almost exactly equalled the rates of their consumption. The yield of Borre sweet lupins was only about one-half of that in the previous experiment. In neither experiment had the lupin seed been inoculated; the satisfactory growth in the first experiment, and the negative response to the nitrogenous fertilizer, indicated that inoculation was not necessary. The nodulation of the plants in the second experiment, however, was not normal, although whether this was due to the lack of moisture or the absence of inoculation is not known.

The growth of the animals on rape was better in the second experiment than in the first, the carcass weights being much higher. Those on the rape crop had a growth rate and carcass weight significantly higher ($P < 0{\cdot}01$) than those on the chou moellier. The growth of the animals on the lupins was poor and hay had to be fed in all replicates.

Discussion

Crop Growth

In both seasons the seeding rates used were associated with a low survival of plants by the time the grazing tests began. Since a reduction of the seeding rate did not increase the number of plants per acre, the loss of plants presumably resulted from causes other than excessive seedling population. The small but definite response of several of the crops to nitrogenous fertilizer, in spite of the dry season, suggests that management of an area to raise the nitrate level of the soil before sowing would be worth while. Greenall [1] has reported yields of rape in New Zealand of 2,600 lb./acre dry matter in a 'very dry' season, and up to 6,800 lb. in a 'wet' season. In contrast to this, the 1957/8 season at Mornington gave yields of rape of about 2,400 lb./acre, and the 1958/9 season gave about 800 lb./acre.

Animal Growth

In both seasons there were two periods of grazing. The first was during January and February, and the second during late February, March, and into April. During the first periods, in both years, the temperatures were very high (80 to 105° F.) and there was no effective rain. However, during the second periods in both years, the temperatures were lower and heavy rain fell.

On no crop tested was the growth of the weaners in the first period of grazing good enough to warrant the expense of growing the crop. There were no marked differences between the growth rates of individual sheep on different crops, but the yields of meat per acre were highest on rape. The weekly growth rates on rape were low at the beginning of each

grazing period but gradually increased. The weekly growth rates on the turnips and sweet lupins were high at the beginning of the grazing periods and then gradually fell as the amounts of dry matter available steadily decreased.

During the 1958/9 season twenty-eight weaners, of the same age and from the same flock as the experimental animals, which were grazing a pasture hay stubble, were weighed regularly from January until April. Although they were not grazed at exactly the same stocking rates as those in the experiments, a comparison with their liveweight changes is revealing. During the period of Experiment 1, when the animals on the fodder crops showed an average liveweight gain of about 3 lb., those weaners on the hay stubble increased, on an average, by 7 lb. However, during the period of the second experiment these same weaners lost an average of 3 lb. while those on the rape crops gained an average of 12 lb.

General Comments

It is extremely doubtful whether, during the seasons 1957/8 and 1958/9, it was worth sowing fodder crops at the end of the spring for grazing during the summer. The lack of moisture at the time when the plants should have been growing most rapidly resulted in dry-matter yields which were only a fraction of those reported from wetter areas, such as New Zealand, where fodder crops are popular and extensively used. In consequence, the growth of the weaners was poor, and there was some evidence that animals grazing a pasture hay stubble grew at a faster rate than those on the experimental crops. However, when late rains occurred the crops grew well and the animal production then increased to satisfactory levels.

In general the rape crop was more satisfactory than any other. Its yields of dry matter per acre were higher than those of the other crops tested, and its conversion into lamb meat was the most efficient of any crop. It also withstood the hot, dry conditions well enough to produce a good regrowth when the rain eventually fell. No clinical cases of rape poisoning occurred, although outbreaks were reported from several properties in the locality during the 1958/9 season. The fact that the weaners on rape in Experiment 1, 1958/9, grew extremely slowly, even though there was a surplus of rape available until the end of the experiment, indicates, however, that subclinical poisoning could have occurred, or that the rape plant was particularly unpalatable at that stage. After the rain had fallen the growth rate of the weaners (Experiment 2, 1958/9) returned to normal.

The general question posed by these results is whether fodder crops are worth growing at all for grazing during hot dry periods of the year. Clearly if they are to be grown for this purpose they should be sown as early as possible in order to receive maximum benefit from preceding rains. Inevitably, however, such crops will be inefficient compared with crops grazed in cooler, wetter, areas or seasons. Either the plants will remain small and immature because of the lack of moisture, or, if sowing has been sufficiently early to enable normal growth to take place before the rains cease, there will be a large loss of dry matter following wilting,

which results from the rapid transpiration loss from the large leaves before they are eaten by the stock.

The decision whether or not to sow crops for grazing in dry periods of the year must therefore depend upon the chances of adequate rain and non-excessive temperatures during the periods of growth and utilization. Where, as in many districts of Victoria, the risk of an unsuitable climate is too great to warrant the expense of a summer-grazed crop, the farmer may be better advised to maintain his weaners in a store condition during the hot, dry season and subsequently fatten them on a fodder crop in the autumn when high crop yields can more reasonably be expected.

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MICRO-NUTRIENT DEFICIENCIES IN ARABLE CROPS IN ROMNEY MARSH. I

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Summary

In a survey of micro-nutrient deficiencies in arable crops carried out on Romney Marsh in 1953, manganese deficiency was diagnosed in 35 out of a total of 172 fields inspected. Manganese deficiency generally occurred in small patches in fields. Mild boron deficiency was found in one instance only, and there was no visual evidence of deficiencies of other micro-nutrient elements. On the fifty-five holdings visited during the course of a survey of fertilizer practice, only four farmers sprayed regularly with micro-nutrients.

Diagnostic spraying trials employing a range of micro-nutrient elements were laid down on twenty-three sites in 1953. Visual responses to manganese were observed in a number of crops.

Twenty experiments on wheat, peas, and potatoes were carried out in 1954–6. Significant yield increases from spraying with a manganese sulphate solution were obtained in three out of eight wheat experiments, four out of six pea experiments, and in none of the potato experiments. Crops on all but one of the sites which gave significant yield increases exhibited visual symptoms of manganese deficiency. This result suggests that worthwhile yield increases in wheat and peas can be obtained by spraying crops which exhibit symptoms of manganese deficiency with a manganese sulphate solution.

A manganese sulphate spray reduced substantially the incidence of marsh spot in peas although it was applied at an earlier stage than is optimum for this purpose; crops were sprayed at a stage when it was considered that the micro-nutrients might have maximum effect on plant growth.

In general there were no significant main effects from spraying with solutions of zinc or copper sulphates on wheat, peas, or potatoes and no consistent interactions between the micro-nutrient treatments or between the major and micro-nutrient treatments. However, a copper sulphate spray caused small significant yield decreases in three of the wheat experiments and one of the pea experiments. It is concluded that no benefit is to be expected from spraying crops on Romney Marsh with solutions of zinc or copper sulphates.

Analyses of plant materials from the experimental sites have revealed generally low levels of manganese but satisfactory levels of zinc and copper.

Responses to nitrogenous top-dressings on wheat and peas, and to the extra dressing at the higher rate of compound fertilizer application on potatoes, have been small; on average, yields were depressed.

Although only incidental to the purposes of these experiments it is noteworthy that spraying potatoes with 'home-made' Bordeaux mixture against potato blight has increased yields in five out of six potato experiments.

ROMNEY MARSH is the collective name for a group of low-lying alluvial areas in south-eastern England, situated mainly in Kent but partly in East Sussex. The area, approximately 100 square miles in extent, is bounded on the east and south by the sea and on the north and west by the old sea cliffs cut in the Wealden hills. The Royal Military Canal, an artificial waterway constructed as a defence measure during the Napoleonic wars, runs close to the old sea cliffs for much of its length. Most of the land is only a few feet above sea-level and is below the level

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of the highest spring tides, the sea being kept out where necessary by means of a system of defence walls. Apart from a small area in Pett Level flooded during the 1939–45 war by the military authorities, there has been very little sea-water flooding in Romney Marsh for many years. The regional drainage of the area is by means of dykes (ditches) and sewers (major watercourses), the latter draining into the sea through a number of tidal outfalls. During the winter months water is discharged into the sea but during the summer water is retained in the various marshes by means of stop-boards and sluices. The area is one of relatively low rainfall (about 25 inches per annum) and the dykes tend to dry out in summer. The water is pumped out of certain low areas in Romney Marsh into the main watercourses.

Although at certain times in the past a substantial area in Romney Marsh has been under the plough, prior to 1939 most of the area was under grass and grazed by the hardy native breed of sheep. Fattening, breeding, and rough-grazing categories of grassland have long been recognized and the reasons for these differences have been the subject of some investigation. Briefly it may be said that soil, management, and herbage composition are all thought to play their part in the production of a fattening pasture. The rough grazing is found mainly on the heaviest, wettest soils and also under dry conditions on shingle. During the summer months Romney Marsh is stocked very heavily with sheep, some of the fattening pastures carrying ten to twelve or more mature sheep per acre, but in the autumn many of the younger animals are sent away to winter on the upland. The winter and early spring climate on Romney Marsh is rigorous, the area being nearly treeless and exposed to winds from the sea.

Although very little of Romney Marsh was under the plough before the last war, a limited acreage of crops for seed (e.g. swedes, mangolds, and peas) has been grown for many years. During the war and since, large areas of grassland have been ploughed for arable cropping, wheat, peas, and potatoes being some of the more important crops. Peas for harvesting dry predominated until recently, but during the last few years there has been a considerable increase in the acreage of vining peas grown. The increase in arable cropping has been accompanied by an improvement in drainage, both regionally and by means of field drainage systems. To some extent there is a conflict of opinion between farmers whose main interest is sheep and farmers whose main interest is arable cropping, the former preferring a higher water-table than the latter because of the supposedly different needs of grassland and arable crops and the fact that the ditches are used as 'wet fences'.

The origin of the soils in Romney Marsh is obscure but it would seem probable that they are partly of fresh water and partly of marine origin. The land has been reclaimed from the sea ('inned') at various dates ranging from Roman or pre-Roman times in the area to the north and east (Romney Marsh proper) up to the early years of this century near New Romney. Most of the south-western part of the area (Walland Marsh) was reclaimed by various church dignitaries and others between the twelfth and sixteenth centuries. The soils in Romney Marsh vary

considerably. Much of the land is heavy in texture and alkaline in reaction (often containing a percentage of calcareous shells) but there are considerable areas of medium-textured soils between Dymchurch and Lydd and in other parts of the Marsh also. Some of these medium-textured soils are mildly to strongly acid. The heavier soils develop a striking 'frost tilth' when ploughed in the autumn and left in a rough state during the winter months. Although the soils as a whole have organic matter contents which are about twice as high as those found generally in the upland soils of south-eastern England, the acreage of organic or peaty soils is extremely limited. The large shingle bank at Dungeness occupies the south-eastern extremity of the area, but little of this is used for agricultural purposes.

During the early years of the wartime ploughing-up campaign considerable difficulty was experienced because of the luxuriant growth and subsequent 'lodging' of cereal crops and to a lesser degree this is still a problem at the present time. In addition certain areas were found to give poor crops under conditions where good crops might have been expected. This led to a series of investigations by Roach and Barclay [1, 2, 3] on the effects of manganese and other micro-nutrient elements on the yields of arable crops. Manganese deficiency, of course, was known to occur in Romney Marsh and had been the subject of investigation prior to 1939. These investigations will be referred to in Part II of this paper. Manganese deficiency was confirmed by Roach and Barclay but the increases obtained by spraying with manganese alone were rarely large enough to suggest that this was the sole cause of poor crops. There were instances where statistically significant yield increases were obtained from spraying with other micro-nutrient elements such as zinc and copper or with various combinations of these micro-nutrient elements. These isolated responses, however, did not appear to establish any general pattern of micro-nutrient deficiencies.

This paper describes further investigations carried out on suspected micro-nutrient deficiencies in Romney Marsh during the period 1953–6.

Details of Experiments

The area included in the investigations was Romney Marsh proper, (see Fig. 1) New Romney Level, Walland Marsh, Denge Marsh, the Upper Level (Shirley Moor), Wittersham Level and Pett Level embracing about 50,000–60,000 acres of agricultural land divided between some 600 holdings (many holdings on Romney Marsh also have land on the upland). At the beginning of these investigations rather less than half the area was in arable crops, most of the remainder being permanent grass.

During the summer of 1953 surveys of fertilizer practice and of the incidence of mineral deficiencies were carried out on a random selection of holdings. Fifty-five holdings were visited for the survey of fertilizer practice and 28 of these were selected for the mineral deficiencies survey, in which 172 arable fields were inspected twice or more during the growing season. Manganese deficiency was found to be the principal micro-nutrient deficiency and was diagnosed in 35 out of the 172 fields

inspected, the crops affected being wheat, oats, peas, sugar-beet, mangolds, turnips for seed, kale, and potatoes. Manganese deficiency occurred generally in small patches in fields. Mild boron deficiency was found (in mangolds) in one instance only and there was not any positive evidence of other micro-nutrient deficiencies. 'Marsh spot' in peas was prevalent in 1953 and was usually preceded by foliage symptoms of manganese deficiency. There did not appear to be any very close correlation between the occurrence of manganese deficiency and type of soil, although it was noted that its incidence was higher on the heavier soils (silts and clays). It was invariably associated with high soil pH, which, however, was not always accompanied by manganese deficiency. On the fifty-five holdings visited in the course of the survey of fertilizer practice, only four farmers sprayed regularly with micro-nutrients.

Twenty-three diagnostic spraying trials employing manganese only and five other elements (boron, copper, iron, molybdenum, and zinc) singly and together with manganese were also carried out in 1953 on crops of wheat, oats, barley, peas, sugar-beet, potatoes, and kale. Visual responses to manganese were not marked in cereals and peas, but were somewhat more definite in sugar-beet and potatoes. Top-dressings of a nitrogenous fertilizer (alone and in combination with spraying with manganese) were applied to the cereals and these often produced marked visual responses surpassing those obtained from any of the micro-nutrient sprays.

During the years 1954–7, twenty main and ten subsidiary experiments (two of the latter on alluvial soils in north Kent) were carried out. The former, which are dealt with in this paper, were primarily concerned with the effects of manganese, zinc, and copper on the yields of wheat, peas, and potatoes, and the latter (to be described separately in Part II), were concerned with the control of manganese deficiency in peas and cereals by conventional and other treatments.

A soil survey of Romney Marsh is at present in progress, but soil maps were not available during the course of these investigations. So far as possible, however, sites were chosen as being representative of the soils of Romney Marsh, most of the sites being on soils which were medium to heavy in texture and alkaline in reaction (pH from 7·0 to 8·3). One experiment (No. 5) was on a light-textured, acid soil (pH 5·2 to 6·4). Levels of 'available' phosphorus were variable and those of potassium generally high. Organic matter content was higher than that found normally in upland soils of south-east England. The locations of the experimental sites are shown on Fig. 1. Main experiments are numbered 1–20, subsidiary experiments 21–28.

Spraying maincrop potatoes against potato blight with proprietary copper fungicides is widely practised on Romney Marsh and it has been difficult to find experimental sites where such sprays have not been applied in previous years. Whenever possible, however, such fields were not chosen for experimental purposes. Experiments were not laid down on fields which had received farmyard manure for the current crop and fertilizers (other than those given experimentally) were excluded from the trial areas. Fields of winter wheat in Romney Marsh are not infrequently

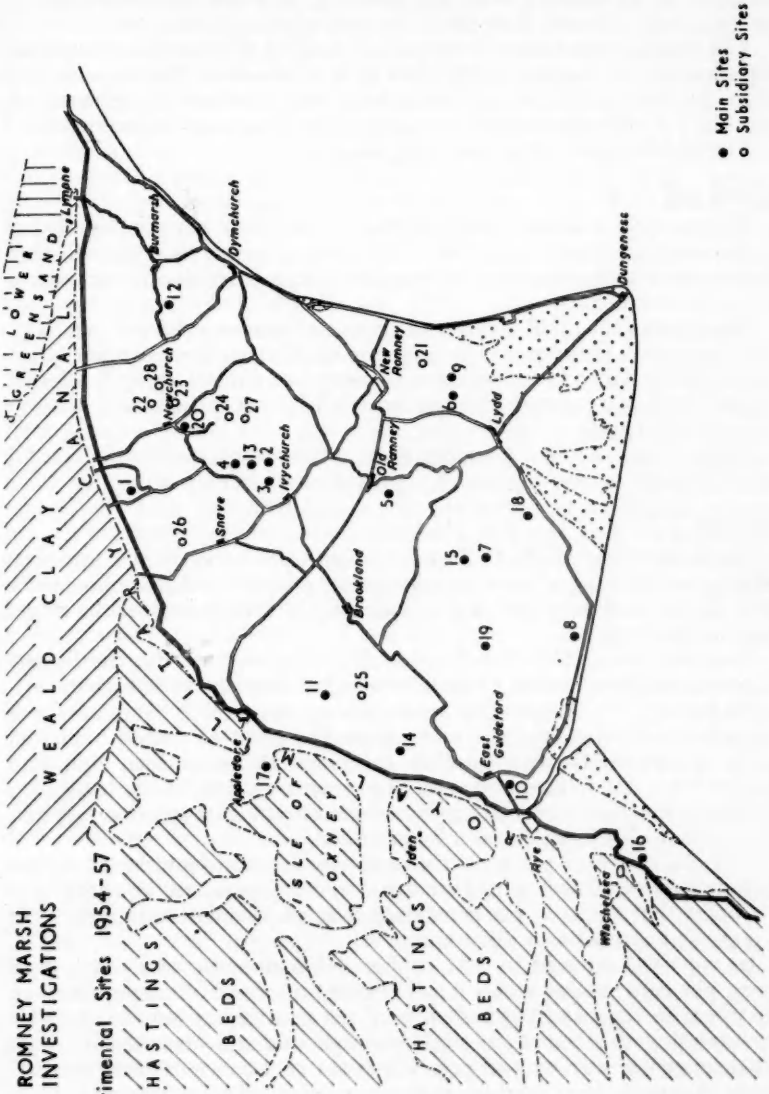
ROMNEY MARSH
INVESTIGATIONS
Experimental Sites 1954-57
WEALD CLAY
LOWER GREENSAND
HASTINGS BEDS
ISLE OF OXNEY
Main Sites
Subsidiary Sites
Burmarsh
Dymchurch
Lympne
Hythe
Sandgate
Folkestone
Newchurch
New Romney
Old Romney
Lydd
Dungeness
Snave
Brookland
Fairfield
East Guldeford
Rye
Winchelsea

FIG. 1

'sheeped off' in spring, but except for site 4 the areas used subsequently for experiments were, if necessary, fenced against sheep.

The experiments were of 2^4 factorial design (2^5 factorial in the potato experiments), consisting of 32 plots in 4 randomized blocks each of 8 plots. Individual plot sizes were $\frac{1}{45}$ acre for the wheat experiments, $\frac{1}{57}$ acre for the pea experiments, and $\frac{1}{114}$ acre for the potato experiments.

The treatments in 1954 and 1955 were:

Wheat and Peas

Nitrogen (N). Nil and 2 cwt. ammonium sulphate per acre, applied as a top-dressing, generally in May. This was given to ascertain whether there were any important interactions between nitrogen and the micro-nutrient treatments.

Manganese (Mn). Nil and 0·5 per cent. manganese sulphate ($MnSO_4.4H_2O$) solution (approximately 1,250 p.p.m. Mn) applied as a foliar spray.

Zinc (Zn). Nil and 0·01 per cent. zinc sulphate ($ZnSO_4.7H_2O$) solution (approximately 25 p.p.m. Zn) applied as a foliar spray (increased to 0·025 per cent. in 1956).

Copper (Cu). Nil and 0·05 per cent. copper sulphate ($CuSO_4.5H_2O$) solution (approx. 125 p.p.m. Cu) applied as a foliar spray.

Potatoes

Basal manuring (NPK). 8 and 16 cwt. per acre, of a compound fertilizer containing 7 per cent. nitrogen, 7 per cent. soluble phosphoric acid (P_2O_5), and 10·5 per cent. potash (K_2O), broadcast over the ridges before planting.

Fungicide spray (S)—'Home-made' Bordeaux mixture for the control of potato blight. Applied twice to two out of four blocks in each experiment during July–August (the reason for applying this treatment to half of each experiment was not to measure the effect of potato blight on yield, but to ensure that possible responses to manganese, zinc, and copper were not reduced because of premature death of the haulm).

Manganese. Nil and 0·8 per cent. manganese sulphate solution (approx. 2,000 p.p.m. Mn) applied as a foliar spray.

Zinc. Nil and 0·01 per cent. zinc sulphate solution (approx. 25 p.p.m. Zn) applied as a foliar spray (increased to 0·025 per cent. in 1956).

Copper. Nil and 0·05 per cent. copper sulphate solution (approx. 125 p.p.m. Cu) applied as a foliar spray.

In 1956 the strength of the copper sulphate spray was reduced to 0·025 per cent. because of a small amount of scorch damage observed on wheat in 1954 and 1955 when 0·05 per cent. spray was used. Notwithstanding this reduction slight damage was still observed in 1956. No damage was seen on peas or potatoes at either concentration. 'Analar' grade chemicals were used for making up micro-nutrient sprays but not for making up Bordeaux mixture. Plots not receiving micro-nutrient sprays were sprayed with water only. A liquid wetting agent was added to sprays (except Bordeaux mixture) at 0·1 per cent. for wheat and peas and 0·2 per cent. for potatoes. To improve wetting of the foliage, 0·2 per cent. of wetter was used for peas in 1956.

Purified water, prepared by passing mains water through a softening plant and then through ion-exchange resins, was used for spraying. In 1956 alone, some 1,000 gallons of purified water were prepared at Wye and transported to Romney Marsh in glass carboys. Micro-nutrient sprays were applied at a rate equivalent to 100 gallons per acre with brass pneumatic knapsack sprayers and hand lances in 1954 and by means of a specially built sprayer in 1955 and 1956. This consisted of a spraying boom supported on a light alloy frame adjustable for varying plot widths and supplied with spray fluid under constant pressure from knapsack containers at each end of the boom (in the type of knapsack container used the spray fluid is contained in a plastic bag kept under pressure). Bordeaux spraying was carried out with brass pneumatic knapsack sprayers and hand lances.

In order to facilitate spraying and harvesting, pathways were cut between the blocks in the wheat and pea experiments and also between individual plots in the pea experiments. An unmanured, unsprayed row was left between plots in the potato experiments. Hessian screens were erected around each individual plot while spraying was in progress, to minimize spray drift (no easy matter in a windswept area). DDT sprays (in purified water) were applied to the pea experiments to control pea moth. No other sprays were applied to any of the sites except No. 14, but hand weeding was carried out where necessary. A herbicidal spray in purified water was applied to the peas on site 14. When herbicidal, fungicidal, insecticidal, or manganese sprays were given by the farmer to the remainder of a field in which an experiment was sited, the experimental area was excluded and screens were erected to minimize spray drift on to the plots.

Micro-nutrient sprays were applied once to the experimental crops, generally in May or June to wheat and peas and in June or July to potatoes. If rain occurred within 24 hours of spraying they were reapplied at half the initial strengths. Wherever possible potatoes were hand planted at regularly spaced intervals.

In 1955 and 1956 bulk soil samples taken from the sites prior to laying down the experiments, and leaf samples taken prior to applying nitrogenous top-dressings or micro-nutrient sprays, were analysed spectrographically by the Macaulay Institute for Soil Research. The analytical results for these samples are given in Table 1.

Wheat plots were harvested with pusher type combine-harvesters, individual plots being made sufficiently wide to allow a small 'discard' on each side of the harvested strip. Only the grain was weighed in 1954 and 1955, but both grain and straw were weighed in 1956. Samples of grain and straw were taken for moisture and nitrogen determinations. Pea experiments were cut by hand and, after preliminary wilting, placed on 'four poles' from which they were threshed with a combine-harvester when dry. The peas were weighed and samples taken from each plot for determinations of moisture and nitrogen, '1,000 pea weights', and marsh spot counts (on cotyledon, plumule, and cotyledon plus plumule). Potatoes were dug by hand, excluding guard rows and small 'discards' at the ends of each plot, and the weight of total tubers recorded.

TABLE 1. *Spectrographic Analysis of Soil (top 6 inches) and Plant Samples from the 1955 and 1956 Experimental Sites*

I. *Soil Samples. Micro-nutrients (other than copper) soluble in 2·5 per cent. Acetic Acid (parts per million). Copper extracted by 0·05M EDTA (parts per million)*

Site	Co	Ni	Mo	Pb	Sn	Zn	V	Ti	Cr	Cu
2	0·53	1·38	< 0·02	< 0·5	< 0·4	3·2	0·6	< 0·5	0·3	2·7
3	0·53	1·73	< 0·02	< 0·5	< 0·4	< 2	0·7	< 0·5	0·2	2·42
4	0·64	1·81	< 0·02	< 0·5	< 0·4	< 2	0·3	< 0·5	0·2	2·55
5	0·72	1·25	< 0·02	< 0·5	< 0·4	3·9	0·2	< 0·5	0·1	1·35
7	0·76	1·27	< 0·02	< 0·5	< 0·4	5·8	0·6	< 0·5	0·3	2·7
8	0·72	1·89	< 0·02	< 0·5	< 0·4	9·3	0·6	< 0·5	0·2	1·50
11	0·78	2·10	< 0·02	< 0·5	< 0·4	4·6	0·7	< 0·5	0·2	2·4
12	0·74	1·74	< 0·02	< 0·5	< 0·4	3·0	0·8	< 0·5	0·2	2·7
13	0·52	1·60	< 0·02	< 0·5	< 0·4	2·9	0·7	< 0·5	0·2	1·94
14	1·15	2·67	< 0·02	< 0·5	< 0·4	6·3	0·8	< 0·5	0·4	1·49
17	0·63	1·31	< 0·02	< 0·5	< 0·4	4·0	0·3	< 0·5	0·3	1·3
18	1·17	2·10	< 0·02	< 0·5	< 0·4	4·4	0·6	0·6	0·3	1·44
19	1·25	2·86	< 0·02	< 0·5	< 0·4	4·7	1·2	< 0·5	0·3	2·15
20	0·55	2·10	< 0·02	0·6	< 0·4	< 2	0·8	< 0·5	0·3	2·22

II. *Plant Samples. Micro-nutrients in Oven-dry Materials (parts per million)*

Site	*Crop*	Co	Ni	Mo	Fe	Pb	Sn	Zn	V	Ti	Cr	Cu	Mn	Ba	Sr
2	Wheat	< 0·03	0·27	0·55	82	1·1	< 1	23	0·16	3·3	0·29	6·0	14	6	17
3	Wheat	0·05	0·39	0·52	148	1·5	< 1	50	0·6	17	0·5	8·2	11	5	14
4	Wheat	0·04	0·40	0·52	123	0·9	< 1	35	0·4	13	0·4	8·3	18	5	16
5	Wheat	0·07	0·44	0·18	83	1·3	< 1	43	0·2	5	0·4	6·7	74	15	8
7	Wheat	< 0·04	0·60	0·57	114	1·6	< 1	38	0·26	6·8	0·42	7·8	22	7	11
8	Wheat	< 0·03	0·30	0·83	82	3·1	< 1	51	0·3	5	0·3	4·6	19	< 4	8
11	Peas	0·10	1·10	1·41	105	0·9	< 1	41	0·27	6·2	0·46	11·2	19	< 4	34
12	Peas	0·20	2·37	1·69	358	1·6	< 1	70	0·48	15	1·03	10·5	20	5	36
13	Peas	0·12	1·47	1·50	228	1·5	< 1	55	1·0	31	0·8	11·4	23	< 4	29
14	Peas	0·11	1·23	0·80	157	2·1	1·3	61	0·6	18	0·6	10·0	10	< 4	34
17	Potatoes	0·20	1·08	0·47	185	2·7	< 1	26	0·77	21	0·65	15·7	24	13	88

Notes

1. Plant and soil samples were taken prior to application of nitrogenous top-dressings or micro-nutrient sprays. Plants selected for analysis were broken off a few inches above ground-level.
2. The figures for plants from sites 18–20 are not given because of heavy soil contamination.
3. The plants on site 5 were growing on an acid soil; the lower molybdenum and higher manganese contents are of interest.
4. The copper and zinc contents of the plant samples are generally normal but certain of the manganese figures are low. Crops on sites 3, 11, 13, and 14 exhibited symptoms of manganese deficiency.

The seasons 1954, 1955, and 1956 were different in several respects. Harvest conditions were good in 1955, but poor both in 1954 and 1956. The latter was a particularly difficult growing season, being excessively dry during the spring and early summer and wet at harvest time. A gale in July 1956 caused much damage to the haulm of potato crops in Romney Marsh.

Results

Some of the more important results for the twenty main experiments are given in Tables 2, 3, and 4.

Table 2 gives the responses of wheat grain, and wheat straw (1956 sites only), to the nitrogen and micro-nutrient treatments together with a number of interactions. It will be seen that the mean yield of 37·8 cwt. of grain per acre, obtained from five winter wheat and three spring wheat experiments (winter wheat mean: 41·8 cwt. per acre; spring wheat mean: 31·2 cwt. per acre) was high, reflecting the inherent fertility of many Romney Marsh soils. The application of a top-dressing of 2 cwt. ammonium sulphate per acre caused a mean grain yield depression of 1 cwt. per acre, largely attributable to site 7 where the plots receiving nitrogen 'lodged' earlier and more severely than the remainder. Spraying the growing crop with a manganese sulphate solution produced a mean grain yield increase of 1·5 cwt. per acre; in the eight experiments three increases and one depression with this treatment were significant at the $P = 0{\cdot}05$ level. The crops on sites 3 and 6, where the largest yield increases were obtained, exhibited marked symptoms of manganese deficiency. The mean effects of spraying with zinc and copper sulphate solutions were small and no symptoms which could be attributed to zinc or copper deficiency were observed in the growing crops. A significant depression from the copper treatment was obtained in three out of four experiments in 1956.

A few of the interactions between the micro-nutrients, and between nitrogen and the micro-nutrients, were significant. There appears to be no consistent pattern in these results and it would appear probable that they are due to chance alone. Wheat straw was weighed in 1956 and here the only effect worthy of note was a mean yield depression of 1·1 cwt. per acre with the copper sulphate spray.

The yields of peas are given in Table 3. The mean yield was 14·0 cwt. per acre, the lowest being 5·0 and the highest 23 cwt. Peas for harvesting dry are a somewhat difficult crop to grow, being dependent on relative freedom from weeds, dry conditions at harvest time, and other factors. The only nutrient treatment to give any marked effect was the application of a manganese sulphate spray, which gave a mean yield increase of 0·6 cwt. per acre; in the six experiments there were four significant increases and one significant depression. Foliar symptoms of manganese deficiency were observed on sites 9, 10, 11, 13, and 14. Marsh spot occurred at all sites; on average, manganese treatment before flowering reduced the incidence by 27 per cent. None of the other treatments had any appreciable effect on marsh spot. It is of interest that marsh spot occurred (and was reduced by a manganese sulphate spray) on the two sites (9 and 12) where manganese treatment gave reduced yields.

TABLE 2. *Yield Responses of Wheat Grain (85 per cent. dry matter) and Wheat Straw (1956 sites only), cwt./acre*

Site	*Grain (G) or straw (S)*	*Year*	N	Mn	Zn	Cu	NMn	NZn	NCu	MnZn	MnCu	ZnCu	MnZnCu	*Mean yield*	*Standard error of difference (14 d.f.)*
							Winter wheat (Cappelle Desprez)								
1. Ruckinge	G	1954	2·4•	0·0	0·5	1·2	−1·5	1·0	1·9	−3·4†	−0·4	−0·7	2·5•	35·4	±1·10
2. Ivychurch	G	1955	−0·7	0·8	−0·7	1·2	1·2	0·6	0·3	0·1	0·1	−0·4	−0·1	45·4	±0·89
3. Ivychurch	G	1956	0·9	3·5†	−0·5	0·3	−0·7	0·1	−1·7	−1·0	−0·9	0·5	1·2	32·0	±1·06
	S	,,	−0·1	1·3	−1·4	−0·5	−0·2	−0·4	0·2	−1·2	0·2	0·1	1·4	20·8	±0·85
4. Ivychurch	G	1956	0·1	0·1	0·9	−1·5†	0·6	0·4	0·2	−0·1	−0·2	−0·2	−0·8	47·9	±0·49
	S	,,	0·4	−0·7	0·0	0·3	−0·4	0·2	−1·0	0·6	1·1	−1·5	1·4	20·1	±0·82
5. Old Romney	G	1956	−1·0	−0·3	0·7	−1·1•	−0·2	0·9	0·4	−0·2	−0·3	0·9	0·5	48·3	±0·51
	S	,,	0·1	0·7	0·1	−2·2	−1·1	−0·2	0·5	1·2	−2·2	0·2	−0·7	21·7	±1·35
							Spring wheat (Atle)								
6. Lydd	G	1954	−3·9	6·5•	−1·8	3·4	3·4	0·3	−1·6	−2·1	0·5	1·6	−3·6	21·6	±2·24
7. Lydd	G	1955	−5·7‡	1·8•	1·1	0·0	2·1•	−0·5	−0·1	1·7•	−2·5†	2·3†	2·4†	37·2	±0·77
8. Broomhill	G	1956	0·3	−0·7•	−0·1	−1·1†	0·0	0·3	0·2	0·3	0·4	0·5	0·5	34·9	±0·27
	S	,,	−0·1	−2·0	0·7	−1·9	−1·0	−0·6	0·1	0·9	1·6	−0·4	−1·5	43·1	±1·82
Mean for grain (8 sites)			−1·0	1·5	0·0	0·3	0·6	0·4	−0·1	−0·6	−0·4	0·6	0·3	37·8	
Mean for straw (4 sites)			−0·1	−0·2	0·2	−1·1	−0·7	−0·3	−0·1	0·4	0·2	−0·4	0·2	26·4	

• = Significant at $P = 0{\cdot}05$ level. † = Significant at $P = 0{\cdot}01$ level. ‡ = Significant at $P = 0{\cdot}001$ level.

TABLE 3. *Yield Responses of Peas (85 per cent. dry matter), cwt./acre*

(Variety: Site 9, Zelka; other sites, Harrison's Glory)

Site	*Year*	N	Mn	Zn	Cu	NMn	NZn	NCu	MnZn	MnCu	ZnCu	MnZnCu	*Mean yield*	*Standard error of difference (14 d.f.)*
9. Lydd	1954	−0·5	−0·9*	−0·5	0·0	0·9*	0·6	−1·2†	0·0	−0·2	−0·4	0·9*	10·6	±0·39
10. East Guldeford	1954	0·4	1·2*	−0·2	−1·9†	0·0	0·7	−0·1	−0·6	−0·5	−0·9	0·3	19·2	±0·53
11. Fairfield	1955	−0·8*	1·5‡	0·5	0·0	0·6*	−0·3	−0·7*	0·0	−0·4	0·5	−0·1	13·0	±0·27
12. Burmarsh	1955	0·6	−0·3	0·9	−0·1	0·0	0·5	1·2	−0·6	0·3	0·0	−0·2	23·0	±0·66
13. Ivychurch	1956	−0·9†	0·8†	0·5	−0·1	0·1	0·2	0·0	−0·1	0·4	−0·2	−0·1	5·0	±0·25
14. Iden	1956	−0·3	1·5*	0·7	−0·9	−0·6	−0·5	−0·4	−0·9	−0·2	0·3	−1·0	13·0	±0·55
Mean (6 sites)		−0·3	0·6	0·3	−0·5	0·2	0·2	−0·2	−0·4	−0·1	−0·1	0·0	14·0	

Percentage Total Marsh Spot—Responses[a]

													Mean percentage of peas affected
9. Lydd	1954	−3	−34‡	−6	0	0	−5	1	9*	13†	−2	8*	50
10. East Guldeford	1954	−5	−31‡	−4	6	2	−6	3	6	1	8	1	69
11. Fairfield	1955	1	−11‡	1	4	−2	0	−4	−3	−1	2	−1	29
12. Burmarsh	1955	0	−13‡	−2	−2	−1	1	1	1	5*	0	2	24
13. Ivychurch	1956	−2	−42‡	0	−4	−7*	3	0	1	1	2	1	42
14. Iden	1956	−2	−31‡	−2	2	−3	1	2	2	−2	0	−1	28
Mean (6 sites)		−2	−27	−2	1	−2	−1	1	3	3	2	2	40

* = Significant at $P = 0{\cdot}05$ level.
† = Significant at $P = 0{\cdot}01$ level.
‡ = Significant at $P = 0{\cdot}001$ level.

[a]. Degree of significance obtained from transformed values.

TABLE 4. *Yield Responses of Potatoes (total tubers, tons/acre)*

(Variety: Sites 15 and 17, Majestic; other sites, King Edward)

Site	*Year*	S	F	Mn	Zn	Cu	FMn	FZn	FCu	MnZn	MnCu	ZnCu	MnZnCu	*Mean yield*	*Standard error of difference (14 d.f.)*
15. Lydd	1954	2·75	−0·33	0·28	−0·62	−0·25	−0·50	−0·06	−0·43	0·81*	0·14	−0·45	0·16	12·19	±0·34
16. Winchelsea	1954	1·92	0·11	−0·22	0·09	−0·18	−0·46	−0·30	−0·12	−0·54	0·76	−0·18	−0·62	5·70	±0·47
17. Stone-in-Oxney	1955	2·91	−0·33	−0·08	−0·13	−0·56	0·76*	0·77*	−0·16	−0·25	−0·25	0·61	0·41	13·61	±0·29
18. Lydd	1956	0·47	−0·39	−0·12	−0·24	0·11	0·17	0·57	−0·16	−0·06	−0·06	−0·16	−0·34	12·61	±0·29
19. East Guldeford	1956	1·20	0·01	0·54	−0·07	−0·35	0·21	−0·07	−0·22	−0·05	0·08	0·04	−0·11	8·99	±0·31
20. Newchurch	1956	−0·27	0·28	0·11	0·48	0·01	−0·22	−0·02	−0·12	0·12	0·26	−0·09	−0·14	6·44	±0·30
Mean (6 sites)		1·50	−0·11	0·09	−0·09	−0·20	−0·01	0·15	−0·20	0·03	0·16	−0·04	−0·11	9·92	

S (Bordeaux mixture, for the control of potato blight)—applied to blocks. Effect of S should not be tested against S.E.
F = Effect of 16 cwt. over 8 cwt. per acre, of compound fertilizer.
* = Significant at $P = 0{\cdot}05$.

In farming practice symptoms of manganese deficiency are often observed too late for spraying to be fully effective and it might be argued that all crops of wheat and peas growing on alkaline or near-alkaline soils in Romney Marsh should be sprayed as a precautionary measure.

The yields of potatoes are given in Table 4. The mean yield was 9·92 tons per acre, the range being 5·70 to 13·61 tons per acre. The sites with rather low yields were planted on rough tilths. Spraying two out of four blocks in each experiment with Bordeaux mixture against potato blight had a marked effect, the haulm on the sprayed blocks remaining green after that on the unsprayed blocks was dead. This treatment gave a mean yield increase of 1·50 tons per acre, the increases in 1956 being smaller than in previous years presumably because the haulm was destroyed prematurely by a gale in that year. There was a small yield decrease on one site (No. 20) in 1956, from the Bordeaux treatment. Giving 16 cwt. per acre, of a compound fertilizer, at planting time had no greater effect on yield than 8 cwt. and there were no marked significant effects from any of the micro-nutrient treatments; of the sixty-six main effects and interactions listed in Table 4, other than the main effect of S which was confounded with blocks, only three (i.e. about 1 in 20) reached significance at the $P = 0{\cdot}05$ level. The only site to exhibit symptoms of manganese deficiency was No. 19 and this was the only potato experiment where an appreciable response to manganese was obtained, although this did not reach significance.

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SOME PESTS AND DISEASES OF SORGHUM, AND THEIR CONTROL IN THE CENTRAL RAINLANDS OF THE SUDAN

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Summary

The fungal diseases and some of the pests of sorghum, at Tozi, in the Central Rainlands of the Sudan, between 1952 and 1956, are recorded. The types of sorghum grown were mainly dwarf varieties, native and imported, suitable for combine-harvesting.

Covered smut (*Sphacelotheca sorghi*), which was severe in the area, was completely controlled by seed dressing with organo-mercurials or TMTD. Other smuts were present but were not of economic importance.

Various fungal leaf spots appeared to be of no economic importance. Charcoal root rot (*Sclerotium bataticola*) was associated with lodging, making mechanical harvesting difficult, but is not believed to be the primary cause in many cases.

Central shoot fly (*Atherigona* sp.) was the major insect pest above the ground. Insecticidal sprays did not control it, but resistant sorghum varieties are being developed. Stem borers, including *Sesamia* sp., were a major cause of lodging, affecting combine-harvesting.

Failure to establish adequate plant populations in the first two years was remedied by insecticidal seed dressings, although the cause was not discovered.

Fungal Diseases

Covered smut. The only serious fungal disease of sorghum at or near Tozi, which lies near the Blue Nile, in approx. latitude 12° 30′ N. longitude 34° 00′ E., was covered smut (*Sphacelotheca sorghi*) which in private cultivations often infected half the heads. At Tozi it was almost completely controlled by seed dressings of organo-mercurials or TMTD (tetra methyl thiuram disulphide). The number of infected plants after seed dressing was infinitesimal. However, in a few cases when seed dressing was inadvertently neglected, heavy attacks resulted.

Loose smut. Three cases of loose smut (*S. cruenta*) occurred on Kavirondo sorghum in 1953, and on several occasions isolated plants in local private cultivations were found with head smut (*S. reiliana*). A Tolyposporium long smut on the wild *Sorghum pupureo-sericeum* was never found on cultivated sorghums, although over 900 varieties were repeatedly grown at Tozi, but another unidentified species of Tolyposporium occurred on a few plants of an imported Japanese variety in 1955.

Leaf spots. Numerous leaf spots occurred, of which the most frequent was *Ramulispora sorghi* (Ell & Ev.), Ol. & Lefevre. This was never severe except for a period in 1953, when, with *Colletotrichum graminicola* (Ces.) Wilson., another frequent leaf spot, it badly damaged eight varieties, all being club headed types normally grown under irrigation farther north. The badly damaged varieties were Safra Kohia and Debekri, both severely attacked, and four Hemaisi types, and 'Cyprus'

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and Hegari, rather less affected. Later in that season, Ramulispora became severe on the imported dwarf variety Plainsman, but as the seed was already nearly mature, probably did little harm. In 1955 it was severe again, on some selections of the feterita Abu Dereira, but nowhere else. The plants attacked were amongst rows of progeny from single heads of the variety, which was being selected for characters suitable for combine-harvesting. It was very noticeable that whilst some lines were almost killed by the fungus, others were but little affected, which promises control by breeding, should this ever become necessary. *Helminthosporium turcicum* Passer. was fairly widespread, but only once recorded as severe, and then on a few plants only. Most leaves which had any infection at all showed spots due to *Gloeocercospora sorghi*, which was never severe.

Leaf spots seemed to be more severe where nitrogen fertilizers had been used.

Sclerotium bataticola was found on the stems of some plants which had lodged, and as lodging seriously affects and may even prevent combine-harvesting, data were gathered to assess the responsibility of the fungus in this. In 1954, in the variety Wad Akr I, a variety selected for combine-harvesting in the Sudan, which was then the principal native type grown, and which was apparently more susceptible to lodging than most, 20 per cent. of the lodged stems in one field were found to have infections of this fungus; but in most cases it was difficult to say whether they preceded or succeeded the lodging. In the previous year the fungus had been found in about a third of the lodged stems of Kaoliang varieties, which were not, however, in general use. Differences in susceptibility to lodging within and between varieties suggested a breeding programme against it; and also suggested, since this difference showed no direct relationship with liability to Sclerotium attack, that lodging might not be due to fungal attack at all, but to inherent structural weakness in some strains.

In 1955 an experiment compared TMTD as a seed dressing at 1/900 w/w[1] and as soil dressings at 1 r.p.f.[2] active ingredient, the soil dressing being watered-on either before planting, or shortly after flowering. Two varieties were used; Plainsman, of American origin; and Bonita × Hegari, a cross with one parent of recent native origin, the latter being normally more liable to lodge than the former. About 22 per cent. of the population lodged in Bonita × Hegari, and only about 8 per cent. in Plainsman. There was no significant effect of treatments, but the TMTD soil dressings appeared to reduce the lodging slightly, and also to improve the stand.

In Bonita × Hegari the mean population per feddan was 66,000, of which 14,400 lodged before harvesting. Of these, nearly two-thirds (9,400) were infested with stem borers; only 980 were found to have infections of Sclerotium. Termites had damaged the stem in 2,400 lodged plants. Another 2,000 had lodged with no obvious cause; inherent structural weakness may account for some lodging.

[1] w/w = parts by weight, chemical to seed.

[2] r.p.f. = rotls per feddan. 1 rotl = 0·98 lb.; 1 feddan = 1·038 acres.

In the less severely affected Plainsman, only 6,800 of the 85,600 plants per feddan lodged. In this variety, an even higher proportion (5,100) had been attacked by stem borer. Only 100 plants had infections of *S. bataticola*: 600 were attacked by termites, and 1,000 lodged through no obvious cause.

The results of this analysis seem to confirm previous suspicions, that even if *Sclerotium bataticola* was involved, it was not the main cause of lodging in sorghum at Tozi. On the other hand, stem borers, which

TABLE 1. *Populations and Incidence of Central Shoot Fly in Large-scale Plantings of Sorghum*

Variety	*Days after planting*	*Population '000 per feddan*	*Central shoot fly incidence*	
			'000 per feddan	*per 1000 plants*
1955: in 12-inch rows				
Bonita × Hegari	26	147·8	9·4	64
	40	124·5	19·0	142
Wad Akr I	40	158·8	11·9	75
	54	146·0	24·7	162
Queensland Kalo	26	147·8	31·4	213
	40	124·5	53·4	389
Plainsman	36	101·2	20·0	198
	50	100·0	42·0	420
1956: in 24-inch rows				
Dwarf White Milo	42	81·1	11·3	140
Kafir Combine 60	42	55·4	2·6	47
Umm Benein	42	81·2	6·0	73
1956: in 30-inch rows				
Wad Akr I	42	118·0	6·0	51
Plainsman	42	103·8	11·4	109
Queensland Kalo	42	94·8	6·9	72

undoubtedly cause lodging, were found in two-thirds to three-quarters of the lodged plants. Roughly half the borers found appeared to be *Sesamia cretica*, but there were two or three others which were not identified.

Following this trial, the selection of new varieties of sorghum for resistance to Sclerotium ceased, and attention was paid to mechanical strength instead.

Central Shoot Fly

Central shoot fly (*Atherigona* sp.) was a severe pest of sorghum at Tozi. Richards, working at Tozi in 1954 [1], had noted that in two varieties, Wad Akr I and Plainsman, both of which are referred to above, infestation at any one date seemed to be a constant proportion of the population of the variety. He concluded that this implied an inherent resistance within the varieties, which suggested a programme of selection.

Varietal differences in susceptibility. Observations were made on which a programme of selection might be based. Table 1 shows the incidence

of central shoot fly, at two dates, on four varieties in common use in 1955, which was a bad season for the pest; and also the incidence on six varieties in 1956, which, being a season of heavy rainfall, was less favourable to the insect, infestations in comparable varieties being generally lower.

Differences in susceptibility to the pest were found between strains of the same variety; in the major type, Wad Akr I, a later selection which it was hoped would give higher yields, proved to be nearly twice as

TABLE 2. *The Effect of Foliar Sprays of Insecticides upon Incidence of Central Shoot Fly Attack in Queensland Kalo Sorghum*

Treatments	*Increase of incidence in plants attacked, '000 per feddan*	
	0–7 days after spraying	*7–23 days after spraying*
	(±0·47)	
None . .	1·92	1·64
Aldrin . .	1·44	1·76
Dieldrin . .	1·42	1·82
DDT . .	0·90	1·74
Endrin . .	0·86	1·98
Mean . .	1·27	1·79

Least significant differences (column 1 only): $P = 0{\cdot}05$: 1·04; $P = 0{\cdot}01$: 1·45

susceptible as the earlier one which it was intended to replace. In the feterita variety, Abu Dereira, which was undergoing selection, progeny of single heads showed a marked variation, from 20 to 80 per cent. infestation. No unfavourable characters appeared to be associated with the resistance, and seed was collected from selected plants of seven varieties for future testing. It was, unfortunately, amongst the complete losses due to flooding in 1956.

Use of insecticidal sprays. At the same time attempts were made to achieve a measure of control more quickly, by the use of insecticidal sprays. Since there was no known stage at which the insect could be attacked in the soil, the programme of soil and seed dressing currently in progress was not expected to have any effect, although Part III of Table 5 (p. 302), summarizing the results of an experiment reported below, showed a reduction of almost 50 per cent. in the incidence of central shoot fly in the first 30 days after emergence, with the use of aldrin seed dressing.

An experiment in 1955 compared sprays of aldrin, DDT, dieldrin, and endrin, each at ½ r.p.f. active ingredient, applied 50 days after planting, on the variety Queensland Kalo, which was usually heavily infested. An area was selected in a large field of the variety, in which preliminary counts showed a uniform level of infestation. Table 2 summarizes the results. About 2,000 plants per feddan became infested in the untreated plots, in the week following treatment; during this time the incidence in plots treated with endrin and DDT was about half

this figure; for endrin the reduction was statistically significant, and that for DDT very nearly so. Dieldrin and aldrin, which were not expected to be effective, seemed to reduce infestation by about 500 plants per feddan. In the 3 weeks following, however, the rate of infestation in the partially protected plots was more rapid, and by harvest time there was a uniform infestation of 35–37 per cent. The inference is that endrin, and perhaps DDT, reduce the attack for about a week, after which the high infestation potential of the insect population enables it to infest all the plants which are susceptible; in this case about 35 per cent.

A second trial was planted very late in the 1955 season, using the systemic insecticide systox. The late planting was deliberate, so as to ensure a heavy infestation, and also in order that preliminary results of first trial should be available for guidance. From those results an additional treatment, the spray of endrin at ½ r.p.f., was included in the later trial. The systox was used as a spray, at ½ r.p.f. active ingredient—a very high rate—and also as a seed dressing. Laboratory tests showed no signs of phytotoxicity when seed was steeped in a 2 per cent. systox solution for several hours; in the experiment the seed treatments were steeped for 20 minutes, and for 1 hour; in the field, both appeared to reduce the emergence by 17–20 per cent. The foliar sprays were applied in 100 gallons water per feddan 21 days after emergence. The general level of infestation was then about 27 per cent., the seed dressings having had no effect, and attack was proceeding very rapidly. In the next 11 days the infestation had risen to 87 per cent., and no effect of either the endrin or the systox was noticed. At harvest time the general level of attack was about 90 per cent., and no harvest was made since few plants headed.

In 1956 endrin and DDT were again tested, systox having been rejected because it showed too little promise to outweigh the risk of using such a toxic substance in unsophisticated regions. It was intended to use both DDT and endrin at ½ r.p.f. in weekly sprays, but the supply of endrin was limited, and it could be applied only at one date, 35 days after planting. The variety Plainsman was used, at two levels of population. The heavy rains and flooding damaged the experiment, although they seemed to reduce the level of central shoot fly infestation. The first DDT sprays severely scorched the young plants, which never recovered, their yield being significantly reduced. There was no other effect of DDT, and no effect of the endrin spray.

Thus, at the present time, no chemical method promises control of *Atherigona* on sorghum, which has in any case a narrow margin of profit, making elaborate spraying uneconomic. Fortunately, breeding of dwarf sorghums from native material is actively going on at Tozi, and selection for resistance to the pest is now a salient feature of that programme.

Losses in Population

Difficulty was at first encountered in establishing adequate populations of sorghum at Tozi. Preliminary work in 1952 had shown that for optimum yield of the imported dwarf varieties then grown, and for the

native dwarfs being developed, populations of 20,000 to 30,000 per feddan were desirable. Later work raised this figure to over 60,000 [2].

Loss of up to 97 per cent. of the seed planted was not uncommon, and the standard seed dressings with organo-mercurial fungicides against smut were ineffective in increasing the establishment. When plants did emerge, up to 30 per cent. might be lost to an unidentified wilt, known by the Arabic name of *hurug*, which is derived from the verb 'to burn', and describes the symptoms. Plants at the 2–4 leaf stage wilted and died with no sign of fungal or insect attack, except that the tap root atrophied before the adventitious roots developed, in a way that suggested insect damage. Hurug appeared to be very closely connected with the pre-emergence losses, and as control of these was effected, the syndrome ceased to be recorded in significant numbers. Although there may be insufficient evidence to justify this, hurug is here regarded as being only a late phase of whatever attack caused the pre-emergence losses.

Tarr, working in the Gedaref area of the eastern Sudan, had found that seed dressings with BHC (lindane) controlled seed-bed losses in population [3], and Richards, working at Tozi in 1953, carried out preliminary tests on small plots with BHC and dieldrin as seed and soil dressings, as a result of which a seed dressing of BHC at 1/1,000 w/w was added to the organo-mercurial already in use, on all the plantings of sorghum at Tozi.

The population losses were so serious in 1953 as to threaten the cultivation of sorghum at Tozi, and attempts were made to identify the cause of the losses. Seed was planted in carefully marked rows, and dug up at intervals, in fields where sorghum plantings had failed in the current year. In a few cases, infections of *Aspergillus niger* and *A. flavus* were found, plainly saprophytic, on seed coats. Most of the seed planted disappeared without trace, and this usually happened within 24 hours of planting. Seed could sometimes be infected with *Rhizopus* sp., and was deliberately infected on some occasions, in order to see if it could destroy the seed without trace in the time. Almost always, most of the seed infected was still present and plainly visible after 24 hours.

To examine further the action of soil-borne pathogens, and also to test a suggestion of soil toxicity, the top 2 inches of soil in areas where plantings had failed was collected and used in pots for germination tests. In the first trial, two batches of fifty seeds were planted in this soil, which was free of all visible insects; one batch was kept dry for 7 days, and the other for 2 days, before being heavily watered. In the former, two seeds were found to be infected with *Rhizopus* sp. on digging up a week later, and one emerged seedling suffered a damping off, apparently due to Rhizoctonia. There were no fungal infections on the more rapidly germinated seed in the other batch. Other trials tested seed dressings of TMTD, mercurials, and BHC, without effect. It seemed plain that whatever the cause of the pre-emergence population losses, it was not normally present in the surface layers of the soil where the seed germinated.

Various suggestions have been made, the most likely of which was by

Tarr, who in the Sudan Gezira found cockchafers to be responsible for similar losses; they were controlled by seed dressings of BHC in the same way [3]. However, Richards, working at Tozi, found few chafers in the soil in 1954, but did not investigate the possibility that they operated mainly at night.

In Richards's trial in 1953 [4], both seed and soil dressings of dieldrin were effective, but soil dressings of BHC, in the circumstances of his trial, appeared to be phytotoxic, and it did not seem that the cost of dieldrin soil dressings could be borne by the crop. Attention was therefore centred on seed dressings, since a dressing of a mercurial or TMTD was already obligatory as a precaution against smut, and the increased cost would be that of the material alone.

TABLE 3. *The Effect of Aldrin and BHC Seed Dressings on Establishment of Sorghum, with Placed or Broadcast Phosphate*

Phosphate treatment	*Populations, '000 per feddan*			
	Insecticides			
	None	*Aldrin*	*BHC*	*Mean*
		$(\pm 6{\cdot}9)^a$		$(\pm 4{\cdot}0)^b$
None . .	6·7	40·4	41·6	29·6
Placed . .	10·8	50·7	42·2	34·6
Broadcast. .	7·1	45·2	43·0	31·8
		$(\pm 4{\cdot}0)^b$		
Mean . .	8·2	45·5	42·3	32·0

Least significant differences: a b

$P = 0{\cdot}05$ 20·7 12·0

$P = 0{\cdot}01$ 28·6 16·5

Use of seed dressings. In 1954 dieldrin was not available in the Sudan, and in a seed-dressing trial aldrin was used in its place, compared at 1/1,000 w/w with BHC at the same rate. Combined with the seed dressings were two phosphate fertilizer treatments; 18 r.p.f. P_2O_5, either placed, or broadcast, before planting. The phosphate was included for three reasons. First, it was suspected that the hurug wilt might be due to phosphate deficiency; secondly, there had been an apparent increase in stand in some plantings with phosphate, in some trials in 1953 [5]; and lastly, in the circumstances of Richards's trial, phosphate, placed by the seed, had appeared phytotoxic [4]. The results, summarized in Table 3, are striking. Out of about 56,000 seeds per feddan planted, only 6,700 plants emerged where no treatment was given, or about 12 per cent. Aldrin seed dressings gave an emergence of about 45,500 plants, or about 80 per cent., and BHC a little less. The phosphate gave indecisive results, apparently tending to improve the stand when placed, although the differences were not statistically significant. The rate of broadcast phosphate was probably too low to be effective in any way. Plants from the aldrin-treated seed emerged rapidly, and flowered and matured over 14 days ahead of the untreated plants, which

were up to a week ahead of the BHC treatments. The vigour of the aldrin-treated plants was exceptional.

In the same year, small-plot field trials were made of the fungicides and insecticides in common use, one trial being planted early, when the soil was fairly dry and emergence slow, and a second, identical later trial, in wet conditions when germination and emergence were much faster. The materials used were, BHC at 1/1,000 w/w, TMTD at 1/900 w/w,

TABLE 4. *The Effect of Seed Dressing with Insecticide and Fungicides on Establishment of Sorghum*

Insecticide	*Populations, '000 per feddan*			
	Active fungicidal ingredient			
	None	*Mercury*	*TMTD*	*Mean*
Part I. Planted 3 August, counted at 24 days				
		$(\pm 2{\cdot}35)^a$		$(\pm 1{\cdot}36)^b$
None	21·8	26·0	23·6	23·8
BHC	32·7	31·5	31·5	31·9
		$(\pm 1{\cdot}67)^c$		
Mean	27·2	28·8	27·6	27·9
Part II. Planted 28 September, counted at 11 days				
		$(\pm 1{\cdot}95)^a$		$(\pm 1{\cdot}12)^b$
None	16·9	16·5	25·9	19·8
BHC	34·3	27·3	28·7	30·1
		$(\pm 1{\cdot}37)^c$		
Mean	25·6	21·9	27·3	25·0

Least significant differences:		a	b	c
Part I:	$P = 0{\cdot}05$	6·96	4·02	4·91
	$P = 0{\cdot}01$	9·44	5·48	6·69
Part II:	$P = 0{\cdot}05$	5·74	3·32	4·06
	$P = 0{\cdot}01$	7·85	4·53	5·54

and an organo-mercurial at a rate to give 1/50,000 w/w Hg. Combinations of the BHC with each of the fungicides were included, at the same rates. The results of both trials appear in Table 4.

In the early trial there was no effect of the fungicides upon population, but the BHC, whether alone or with either fungicide, raised the stand by roughly 50 per cent. The mean population of the experiment, 28,000 plants per feddan, represented less than half the 68,000 seeds planted; the emergence was very slow, and was not complete before 24 days.

In the later experiment, from the same seed rate, the mean experiment population was only 25,000 per feddan, although emergence had been more rapid, being complete after 11 days. Untreated seed gave a stand of about 17,000, a relatively better performance than in the earlier trial. BHC nearly doubled this figure, and the TMTD quite unexpectedly

TABLE 5. *The Effect of Insecticidal Seed Dressings on Establishment, Yield, and Incidence of Central Shoot Fly on Two varieties of Sorghum*

Variety	*Insecticide treatment*				
	None	*Aldrin*	*BHC*	*Dieldrin*	*Mean*
Part I. Population at harvest, '000 per feddan					
		(±4·8)[a]			(±2·4)[b]
Plainsman	43·8	35·4	59·0	53·6	48·0
Bonita	36·9	41·9	50·2	53·0	45·5
		(±3·4)[c]			
Mean	40·4	38·6	54·6	53·3	46·7
Least significant differences:		a	b	c	
$P = 0·05$		9·8	4·9	6·9	
$P = 0·01$		13·2	6·6	9·3	
Part II. Yield, r.p.f.					
		(±250)[a]			(±125)[b]
Plainsman	2,088	2,053	2,031	2,336	2,194
Bonita	1,911	1,699	2,088	2,088	1,946
		(±177)[c]			
Mean	2,000	1,876	2,194	2,212	2,070
Least significant differences:		a	b	c	
$P = 0·05$		530	265	375	
$P = 0·01$		743	372	525	
Part III. Central shoot fly incidence, % of population					
1. at 30 days:					
Plainsman	2·3	1·2	1·4	2·1	1·8
Bonita	1·3	0·5	1·0	0·9	0·9
Mean	1·8	0·9	1·2	1·5	1·4
2. at 42 days:					
Plainsman	12·5	11·0	14·2	9·7	11·8
Bonita	5·3	6·4	6·2	5·7	5·9
Mean	8·9	8·7	10·2	7·7	8·9
3. Total recorded:					
Plainsman	14·8	12·2	15·6	11·8	13·6
Bonita	6·6	7·1	7·2	6·6	6·8
Mean	10·7	9·7	11·4	9·2	10·2
Part IV. Heading and anthesis at 52 days, '000 per feddan, Plainsman only					
Heading: (±1·69)[a]	12·1	12·4	10·8	12·4	11·9
Anthesis (±0·55)[b]	2·0	2·0	1·3	2·2	1·9
Least significant differences:		a	b		
$P = 0·05$		3·6	1·2		
$P = 0·01$		4·9	1·6		

improved the population by some 9,000. Where TMTD and BHC were used together, however, the effect was rather less than that of using BHC alone, whilst the reduction in stand by combining the mercurial with the BHC reached the $P = 0{\cdot}05$ level of statistical significance.

These trials, confirming the results of Tarr [3] and Richards [4], presented no reason for changing the practice, adopted in 1954, of seed dressing with an organo-mercurial BHC seed dressing (Mergamma B) on bulk plantings. Satisfactory populations were established in this way for large-scale production.

There remained to be investigated the possible advantages of dieldrin, since this insecticide had shown promise in other fields at Tozi, and the curious acceleration of growth with the aldrin seed dressing. With regard to the latter, some work by Walton at Tozi during the dry season of 1955 was of interest [6]. Investigating the different rates of germination in different varieties of sorghum, he found that the presence of a horny layer in the endosperm greatly retarded germination in conditions of low water availability. The variety Plainsman, which had been used in the aldrin seed-dressing trial in 1954, was one which had the horny endosperm layer; it appeared that with the seed dressing its rate of development had been more nearly that of similar varieties lacking the layer.

In an experiment in 1955, in which aldrin, dieldrin and BHC were compared as seed dusts, two varieties of sorghum were used: Plainsman; and Bonita × Hegari, which is very similar in habit, but lacks the horny layer in the endosperm of the seed. The conditions for germination were good, and about 33 per cent. of the untreated seed, or some 40,000 plants per feddan, emerged. Table 5, part I, gives the detailed results. Dieldrin and BHC both increased the stand to about 51,000, but aldrin, for no obvious reason, had no effect. The increases in stand were reflected in slight, but not statistically significant, increases in yield, from about 2,100 to 2,300 r.p.f. in Plainsman, and from 1,900 to 2,100 r.p.f. in Bonita × Hegari. The latter flowered and matured about 10 days ahead of Plainsman, although it had not been noticeably more rapid in emergence, and there was no effect of any treatment on the date of heading of either variety.

During 1955 seed for large-scale plantings of sorghum was dressed with dieldrin instead of BHC as the insecticide component, simply for convenience, as this mixture was in general use on the station. High rates of planting, up to 180,000 seeds per feddan, aiming at final stands of about 100,000, proved in fact too successful, some fields having up to 160,000 plants per feddan. Post-emergence losses in population were heavy in these dense stands. In one field of Wad Akr I sorghum, a stand of 113,300 plants at 14 days after planting was reduced to 90,000 by the 60th day. These losses were due almost entirely to lodging, either from weakness due to the close spacing, or to stem-borer attack, with subsequent rapid destruction by termites; or to attack by central shoot fly, which so weakened some plants that they were unable to compete with the healthy ones. All the significant losses took place after the plants were well past the stage when hurug might, at one time, have been the

cause, the biggest losses occurring between 29 and 42 days, at which stages the stands were 111,300 and 104,500 respectively, a loss of 6,800 plants per feddan, or over 500 a day.

However, although post-emergence population losses are by no means negligible, they are not important in same way that the pre-emergence losses were; control of the later losses would certainly be expensive, if it could be done at all, and so long as a good measure of control of the all-important pre-emergence losses can be cheaply obtained with seed dressings of BHC, it is easy and almost costless to increase the seed rate to compensate for the later losses.

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THE MINERAL CONTENT OF ABACA IN RELATION TO FERTILIZER USE IN COSTA RICA

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Summary

Chemical analyses of different parts of abaca plants, grown with various fertilizer treatments, are presented and discussed.

The content of nitrogen, phosphorus, and potassium was highest in the lamina of the youngest leaf and decreased in the samples from the older leaves.

The nitrogen content of the leaf lamina decreased, and the potassium content increased, from tip towards base of leaf.

The nitrogen or potassium content of the leaf lamina was increased by nitrogen or potassium fertilizers respectively. The phosphorus content was not consistently influenced by phosphorus fertilizers.

The lamina of the third leaf proved satisfactory for study of the nutrient status in respect of most of the elements studied, but where the primary interest is the potassium status, the basal part of the pseudostem is preferable.

The agreement of the data reported here with those obtained for Lacatan bananas in Jamaica is noteworthy, having regard to the differences in species, soils, and climate, as between Jamaica and Costa Rica. The differences in response to fertilizer applications can be reconciled through the differences in the kind and amount of plant material removed in the harvested crop: in banana culture only the fruit is removed, while with abaca the entire pseudostem is harvested.

THE mineral content of a plant growing on a certain soil under specific environmental conditions will represent the ability of that plant to extract from the soil those elements necessary for its life functions. The amounts and proportions of mineral elements in a normal vigorous plant commonly represent the optimum for that plant grown under specific conditions of environment.

Since abaca (*Musa textilis* Nee), otherwise known as Manila hemp, requires special climatic and soil conditions, its cultivation will always be limited to a few specific regions. A warm climate, with high relative humidity, and rainfall uniformly distributed throughout the year, best meets the requirements of this truly tropical plant [1]. Robinson and Johnson [2] state that 'abaca must have a fertile soil for economic production' and indicate that fertilizers may be required. Bally and Tobler [1] also indicate that many soils could be thoroughly depleted of their native plant nutrients in 10 to 15 years by harvests of abaca. Therefore, an effective programme of abaca production must include the use of fertilizers or manures.

The most certain method to determine the effects of fertilizers on crop yields is by field trials, but these are expensive. Other means of assessing or predicting fertilizer responses or requirements are (1) soil tests and (2) plant analyses. The relation of chemical composition of plants to

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plant nutrition forms the major part of a report by Goodall and Gregory [3]. Most of the reported work, however, refers to temperate-zone or sub-tropical plants. Few papers have been published on the mineral content and fertilizer response of abaca or closely related species.

Hewitt [4] has published data showing the effect of fertilizers on the mineral nutrient content and yield of the Lacatan banana (*Musa paradisiaca* L.). The work reported here on abaca is considerably more detailed than that of Hewitt, but it accords with his findings and perhaps indicates that some plant-part other than the third leaf might be a more useful diagnostic sample.

Materials and Methods

In mid-1950 a $3 \times 3 \times 3$ factorial fertilizer experiment was begun on Celina silt loam in Section 30 of Luzon farm on the United Fruit Company's Good Hope Plantation in Costa Rica. The area was classified as abaca productivity Class III by Robinson and Striker [5]. In late 1956 and early 1957 plants from selected treatments were sampled for chemical analysis. Annual fertilizer applications, and the yields during the 6-year period, are presented in Table 1 for the treatments sampled.

TABLE 1. *Fertilizer Treatments and Yields of Fresh Unpeeled Abaca Stalk (Pseudostem)*

Annual treatments (lb. per acre)			*Yields (lb. per acre)*	
N	P_2O_5	K_2O	*6-year total (1951–6)*	*Mean per year*
0	0	0	327,293	34,812
50	50	250	416,246	69,374
200	150	500	507,087	84,514
200	0	0	355,675	59,279
0	150	0	366,841	61,140
0	0	500	456,401	76,066

The best time for harvesting abaca stalk (pseudostem) material for fibre extraction is at flowering, or 'shooting'. This is a well-advanced stage in the life cycle of the plant and occurs about 18–24 months after the plant sucker has emerged above the ground surface. Plants in which the bud with its contained flowers is visible in the leaf axil at the apex of the pseudostem are said to be 'shot' plants.

One mature shot plant from a border row of each plot of the selected treatments was harvested. Data taken at the time of sampling included:

Circumference of the pseudostem at the plant base (ground surface).
Circumference of the pseudostem 1 metre above the ground surface.
Total height of plant from ground surface to the upper leaf axil.
Length and width of each leaf.

Detailed sampling of each plant was done in the field. The blade of each leaf was divided into three parts (apical, central, and basal) and separated from the midrib. Each midrib was divided into two samples, apical and basal. Leaves were numbered from the top downward (youngest to oldest). The blades of a few small leaves were divided into

only two samples, and then the entire midrib was taken as a single sample. Petioles of the leaves, from leaf laminae to the point of divergence from the pseudostem, were taken as a single sample. The fruit, flower bud, and the small covering leaf were taken together as one sample from each plant. The pseudostem was sampled by cutting a transverse section of variable thickness from the base of the plant, and at intervals of 1 metre above, until the point of branching of the main leaves was reached. A section at the top of each pseudostem was also collected.

All samples were dried at 70° C. and ground in an intermediate Wiley mill to pass a 20-mesh sieve. Ground samples were stored in glass jars with close-fitting lids until subsampled for analysis. Repeated tests showed that no redrying was required.

Nitrogen in 0·1-g. samples was determined by micro-Kjeldahl procedure. One-g. samples were used for phosphorus, potassium, calcium, and magnesium. Duplicate 1-g. samples were ashed by heating with enough (about 10 ml.) of a 1:5 mixture of 60–70 per cent. perchloric and concentrated nitric acids to bring about complete solution. The colourless opalescent solution was diluted with water to 100 ml., filtered through dry paper to remove dehydrated silica, and aliquots were taken for the following determinations:

Potassium: by the internal-standard method of flame spectrophotometry.

Magnesium: by a thiazole-yellow procedure modified from that of Drosdoff and Nearpass [6]. Colour intensity of the lake was determined with a photoelectric colorimeter.

Phosphorus: by a modification of Bray's [7] phosphomolybdate-blue procedure, and photoelectric colorimeter.

Calcium: by titration of the precipitated oxalate by the AOAC method for plants [8]. The precipitating solution was prepared according to Smith, Moodie, and McCreery [9].

Results

Results of the chemical analyses of the dry matter of the above samples are presented in Tables 2, 3, and 4, in the Appendix to this paper. The following observations are made from these data, and related to the findings of Hewitt [4] for bananas.

Leaf Blades

Nitrogen. Decreased with age of leaf, similarly to bananas, except that Hewitt found higher nitrogen content in the third leaf than in the first (youngest).

Decreased from the tip of the leaves toward the base.

Increased slightly in the centre and basal sections but showed no change in the apical parts when the intermediate level of fertilizers was applied.

Increased when the high level of nitrogen was applied, as in bananas.

Increased when the high level of potassium was applied, as in bananas.

Phosphorus. Decreased with the age of the leaf, as in bananas.
Remained rather uniform regardless of treatment, much as in bananas.
Tended to increase when the high level of potassium was applied.
Potassium. Decreased with the age of the leaf, as in bananas.
Increased from the leaf tip toward the base.
Intermediate level of fertilizers increased the potassium content of the centre and basal portions but did not change that of the apical part.
Was highest with the high level of potassium used alone.
Calcium. Tended to increase with the age of the leaf but was inconsistent.
Magnesium. Highest content was found where intermediate level of fertilizers, and where high nitrogen alone, were applied.
The high-phosphorus treatment decreased the magnesium content.

Leaf Midrib

Nitrogen. Tended to decrease with age of leaf.
Apical part had more nitrogen than the basal part.
Only slight differences occurred with different treatments.
Phosphorus. Not related to age of leaf.
Apical part had higher content than basal.
High level of nitrogen decreased phosphorus content, which was highest where phosphorus was applied alone and next highest where potassium was applied alone.
Potassium. Decreased with age of leaf.
Apical parts had highest content when no potassium was applied but basal parts were highest when high level of potassium was applied or where phosphorus was used alone.
Calcium. Tended to increase with age of leaf except where potassium was used alone, where the reverse was true.
Apical parts were higher in calcium than basal parts.
Intermediate level of fertilizer applications gave highest calcium content followed by the nitrogen-alone treatment.
Was lowest with the potassium-alone treatment.
Magnesium. Tended to increase with age of leaf.
Apical parts tended to be higher in magnesium than basal parts.
Considerable variation with treatment; lowest values were found with the high-phosphorus treatments.
Was relatively higher with the nitrogen-alone treatment.

Flower and Fruit

Nitrogen. Increased with any fertilizer treatment, especially with those containing nitrogen.
Phosphorus. Decreased with fertilizers not containing phosphorus.
Potassium. Was highest in this plant part.
Increased when high level of potassium was used but decreased with other fertilizers.

Calcium. Was highest with phosphorus alone.
Was lowest with potassium alone.

Magnesium. Only slight differences occurred except with the high level of all three fertilizers, which gave lowest magnesium content.

Leaf Petioles

Nitrogen. Slight increases were associated with application of fertilizers, especially nitrogen.

Phosphorus. Decreased by high nitrogen with or without phosphorus.
Increased by potassium alone.

Potassium. Increased by application of potassium fertilizer.

Calcium. Was highest with intermediate level of fertilizer treatment.
Was lowest with high level of all three fertilizers.

Magnesium. Was lowest with potassium alone.
Was highest with the intermediate level of fertilizer treatment.

Pseudostem

Nitrogen. The greatest variation, in relation to the treatment, occurred 1 metre above the base, and seemed to represent the minimum nitrogen content. Above or below this height nitrogen increased.

Phosphorus. Phosphorus applied alone increased the phosphorus content.
High nitrogen decreased phosphorus content but other treatments seemed not to affect it.

Potassium. Tended to decrease from the top downward until 1 metre above the base.
The basal section had higher potassium content than other sections.
The basal section was the most sensitive part of the plant for relating potassium content to use of potassium fertilizer.
The potassium content of the basal section with high level of potassium fertilizer was about eight times that where no potassium had been applied.

Magnesium. Content was variable but tended to be highest toward the base. The decrease of magnesium content with increasing amounts of fertilizer was evident. This cannot be related to any one element, but it may be associated with the high-potassium treatment, since magnesium is very low in the potassium alone treatment also.

Discussion

Table 1 shows that the lowest yields were obtained where no fertilizer was applied and that the high level of fertilizer application produced the highest yields. Statistical analysis of yield data from all plots in this trial shows significant yield increases only for potassium treatments; although complete (NPK) fertilizer treatments gave still higher yields, the differences were not significant. The total increase of nearly 180,000 lb. per acre, obtained over the 6-year period with the high level of fertilizer, corresponds to an annual average of almost 30,000 lb. of additional stalk per acre. Where potassium was used alone the 6-year total increase

was nearly 130,000 lb. per acre, or an average annual increase of about 21,500 lb. per acre. The magnitude of these increases is especially encouraging when compared with the 10-year (1945–54 inclusive) average annual yield of little more than 21,000 lb. per acre for the section surrounding the experimental plots. Further, these increases were obtained on soil which was classed by Robinson and Striker [5] as border-line for the economic production of abaca.

The present work on abaca fully supports Hewitt's [4] selection of the leaf blade of the third leaf as the best single sample for diagnosis of nutrient status. When samples are to be taken from a standing plantation for determination of more than one element it is recommended that the central part of the blade of the third leaf from the top be used. Ample variation in content of most elements, in relation to fertilizer treatment, occurred in this plant part. However, it should not be overlooked that, in the case of abaca, samples of the basal parts of pseudostems can be obtained from a plantation during the harvesting operations, since the entire pseudostem is cut at the time of harvest, whereas in banana culture only the fruit is removed. This difference in the amount of plant material removed in these two crops may also serve to account for the differences in their responses to fertilizer applications.

The findings from chemical analyses of plant samples can be used to determine the kind and amount of fertilizer application necessary to correct nutrient deficiencies, when correlated with the results of field experiments with fertilizers. In other work (unpublished) substantial changes in chemical composition and appearance of the plants were brought about by fertilizers within 4 months of application.

The most suitable time of sampling, i.e. physiological stage in the plant-life cycle, has not been thoroughly investigated in abaca. Machado [10] studied the uptake of mineral nutrients by the plantain. He related the quantity of various nutrients to the physiological age of the plant and the amount of dry matter produced. His results indicate that the greatest rate of increase in dry matter occurred during a period from $1\frac{1}{2}$ months after flowering to harvest of the fruit. The next highest rate was at about the time of flowering, or shooting. The uptake of mineral nutrients followed a similar pattern. Thus the time of shooting represents a stress period in the life cycle, and the nutrient content at that time should be a good measure of the nutritional status of the plants. Hewitt [4] states that the nutrient content of banana leaves was generally higher at the time of shooting than at a later period.

Comparison of the mineral content of abaca with that of Lacatan bananas, as found by Hewitt, shows that abaca is somewhat lower in nitrogen, phosphorus, and potassium in the same leaf sections, and that the range of values for all three elements is smaller in abaca than in bananas. The lower limit for nitrogen, reported for bananas, is 2·3 per cent., and that for abaca 1·8 per cent. The upper limits are 3·8 and 2·6 per cent. respectively. Comparative values for phosphorus (as P_2O_5) are 0·53 to 0·81 per cent. for bananas and 0·39 to 0·54 per cent. for abaca. Potassium (as K_2O) ranges from 2·0 to 5·3 per cent. for bananas and from 1·6 to 2·7 per cent. for abaca in the central portion of the third leaf.

Thus it may be seen that the upper limit of the mineral content of abaca is only slightly higher than the lower limit of that for bananas.

The implications of this difference in level of mineral content of these botanically similar plants are not clear. Resistance to disease may perhaps be associated with lower requirements of abaca for plant nutrients. Lower demands of abaca for mineral nutrients could possibly mean that a soil unable to maintain bananas could provide adequate quantities of plant nutrients for good growth of abaca even to the extent of decreasing the severity of attack by an organism known to cause disease in both plants.

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APPENDIX

In Tables 2, 3, and 4 below are recorded the detailed results of the analysis of the samples of the various parts of the abaca plants grown with various fertilizer treatments (see p. 306). All the data recorded in these tables refer to *the percentage of the nutrient elements* in the oven-dry material, viz.:

Nitrogen, expressed as		N
Phosphorus	,,	P
Potassium	,,	K
Calcium	,,	Ca
Magnesium	,,	Mg

The *fertilizer treatments* were:

$N_0P_0K_0$ = no fertilizer
$N_2P_0K_0$ = 200 lb. N per acre
$N_0P_2K_0$ = 150 lb. P_2O_5 per acre
$N_0P_0K_2$ = 500 lb. K_2O per acre
$N_1P_1K_1$ = 50 lb. N + 50 lb. P_2O_5 + 250 lb. K_2O per acre
$N_2P_2K_2$ = 200 lb. N + 150 lb. P_2O_5 + 500 lb. K_2O per acre

Leaves are numbered 1, 2, 3, &c., downwards from the topmost (youngest) leaf. The figures given as *averages* are arithmetic means.

TABLE 2. *Mineral Content of Abaca Leaf Blade Samples in Relation to Fertilizer Treatments Applied*

Nutrient element		N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Fertilizer treatment	*Leaf number*	*Apical part*					*Central part*					*Basal part*				
$N_0P_0K_0$	1	2·25	0·28	2·37	1·20	0·27	..	..	..	..	..	1·93	0·28	2·48	1·42	0·24
	2	2·29	0·28	1·97	1·15	0·23	..	..	..	..	..	2·14	0·27	2·17	1·32	0·30
	3	2·07	0·23	1·69	1·10	0·26	1·81	0·22	1·84	1·10	0·29	1·63	0·19	1·73	1·04	0·29
	4	1·85	0·25	0·83	1·99	0·47	1·85	0·27	1·04	1·75	0·46	1·82	0·22	1·19	1·96	0·43
	5	2·12	0·24	1·27	1·43	0·45	2·05	0·23	1·50	1·89	0·41	1·87	0·23	1·69	1·38	0·37
	6	1·59	0·16	0·47	3·14	0·63	1·62	0·19	0·62	3·03	0·72	1·52	0·16	0·87	3·01	0·78
	Average	2·03	0·24	1·43	1·67	0·38	1·83	0·23	1·25	1·94	0·47	1·82	0·23	1·69	1·69	0·40
$N_1P_1K_1$	1	2·42	0·21	2·13	1·31	0·31	2·28	0·22	2·34	1·36	0·30	2·00	0·22	2·66	1·43	0·31
	2	2·46	0·21	1·88	1·15	0·37	2·27	0·21	2·06	1·38	0·32	2·09	0·20	2·34	1·33	0·36
	3	2·23	0·18	1·59	1·17	0·34	2·05	0·17	1·89	1·55	0·33	2·02	0·18	2·17	1·37	0·27
	4	1·88	0·14	1·24	1·21	0·33	1·99	0·15	1·64	1·41	0·39	1·95	0·15	2·01	1·35	0·32
	5	1·83	0·13	1·34	1·38	0·34	1·78	0·12	1·50	1·32	0·30	1·96	0·13	1·80	1·40	0·31
	6	1·62	0·11	0·95	1·45	0·41	1·68	0·11	1·34	1·38	0·37	1·66	0·11	1·62	1·32	0·38
	Average	2·07	0·16	1·52	1·28	0·35	2·01	0·16	1·79	1·40	0·34	1·95	0·17	2·10	1·37	0·32
$N_2P_2K_2$	1	2·01	0·16	1·46	2·49	0·54	..	..	..	..	..	2·18	0·20	2·24	2·78	0·65
	2	2·18	0·26	1·51	2·25	0·54	2·16	0·27	1·61	2·40	0·43	2·05	0·18	1·96	2·57	0·57
	3	1·79	0·17	1·19	2·47	0·51	1·95	0·18	1·71	2·63	0·56	2·02	0·19	2·25	2·31	0·36
	Average	1·99	0·20	1·39	2·40	0·53	2·05	0·23	1·66	2·51	0·50	2·08	0·19	2·15	2·55	0·53
$N_1P_0K_0$	1	2·71	0·20	1·78	1·46	0·46	..	..	..	..	..	2·36	0·24	1·87	1·41	0·39
	2	2·62	0·08	1·35	2·17	0·53	2·60	0·22	1·86	1·66	0·47	2·41	0·20	2·03	1·67	0·39
	3	2·54	0·19	1·07	2·15	0·56	2·59	0·19	2·22	1·23	0·52	2·47	0·20	1·53	1·96	0·49
	4	2·34	0·19	1·03	2·57	0·53	2·34	0·19	2·29	1·38	0·52	2·39	0·21	1·65	2·35	0·52
	5	2·07	0·17	0·70	2·94	0·72	2·18	0·20	2·83	1·05	0·62	2·22	0·18	1·23	2·89	0·61
	6	1·98	0·17	0·65	3·37	0·68	2·10	0·18	3·51	0·83	0·60	1·96	0·19	1·02	3·38	0·64
	Average	2·38	0·17	1·10	2·44	0·58	2·36	0·20	2·54	1·23	0·55	2·30	0·20	1·55	2·28	0·51
$N_0P_1K_0$	1	2·27	0·08	1·75	1·50	0·22	..	..	..	..	..	1·87	0·24	1·99	1·96	0·26
	2	2·26	0·23	1·35	1·09	0·24	2·15	0·21	1·55	1·19	0·19	1·89	0·25	1·82	1·43	0·22
	3	1·79	0·21	1·00	1·35	0·26	1·98	0·19	1·30	1·34	0·22	1·86	0·20	1·56	1·46	0·21
	4	1·07	0·23	0·42	2·45	0·31	..	..	..	..	..	1·41	0·15	0·96	2·18	0·24
	Average	1·85	0·19	1·13	1·60	0·26	2·06	0·20	1·42	1·26	0·20	1·76	0·21	1·58	1·76	0·23
$N_0P_0K_1$	1	2·37	0·26	2·65	0·91	0·41	..	..	..	..	..	2·17	0·30	3·12	1·29	0·40
	2	2·50	0·23	2·36	1·13	0·43	2·38	0·23	2·73	1·22	0·40	2·79	0·33	4·23	1·75	0·58
	3	2·31	0·24	1·97	1·14	0·45	2·24	0·24	2·21	1·12	0·39	2·26	0·24	2·37	1·22	0·35
	4	2·13	0·24	2·03	1·31	0·46	2·05	0·24	2·40	1·35	0·42	2·11	0·24	2·82	1·32	0·50
	Average	2·33	0·24	2·25	1·12	0·44	2·22	0·24	2·45	1·23	0·40	2·33	0·28	3·13	1·39	0·46

TABLE 3. *Mineral Content of Abaca Leaf Midrib Samples in Relation to Fertilizer Treatments Applied*

Nutrient element		N	P	K	Ca	Mg	N	P	K	Ca	Mg
Fertilizer treatment	*Leaf number*	*Apical part*					*Basal part*				
$N_0P_0K_0$	1	0·41	0·12	1·58	1·50	0·16	..	..	..	..	..
	2	0·46	0·15	0·84	1·51	0·21	0·30	0·12	0·88	1·77	0·19
	3	0·41	0·18	0·46	1·43	0·27	0·26	0·10	0·48	1·47	0·25
	4	0·48	0·24	0·19	2·91	0·63	0·29	0·14	0·02	2·21	0·54
	5	0·40	0·17	0·17	1·98	0·44	0·30	0·08	0·18	2·14	0·56
	6	0·41	0·25	0·08	3·62	0·94	0·26	0·15	0·06	3·14	0·90
	Average	0·43	0·18	0·55	2·16	0·44	0·28	0·12	0·32	2·15	0·49
$N_1P_1K_1$	1	0·67	0·25	1·62	3·67	0·54	0·39	0·11	1·08	3·75	0·60
	2	0·51	0·21	1·22	4·20	0·48	0·36	0·13	1·32	3·78	0·58
	3	0·47	0·16	1·05	3·91	0·54	0·29	0·09	0·83	2·75	0·33
	Average	0·55	0·21	1·30	3·93	0·52	0·35	0·11	1·08	3·43	0·50
$N_2P_2K_2$	1	0·52	0·14	1·81	1·71	0·22	0·39	0·10	2·27	1·55	0·14
	2	0·50	0·14	1·36	1·42	0·22	0·34	0·08	1·81	1·62	0·16
	3	0·48	0·17	0·95	1·61	0·17	0·34	0·06	1·62	1·63	0·08
	4	0·56	0·09	0·83	1·61	0·18	0·34	0·01	1·42	1·47	0·10
	5	0·51	0·05	0·97	1·80	0·21	0·30	0·04	1·02	1·23	0·18
	6	0·48	0·05	0·87	1·91	0·22	0·32	0·04	1·12	1·48	0·18
	Average	0·51	0·11	1·13	1·68	0·20	0·34	0·06	1·54	1·50	0·14
$N_2P_0K_0$	1	0·39	0·07	1·95	1·82	0·48	..	..	..	..	..
	2	0·54	0·13	0·57	2·49	0·52	0·35	0·06	0·76	1·61	0·42
	3	0·50	0·10	0·48	2·90	0·54	0·31	0·08	0·38	2·05	0·54
	4	0·50	0·14	0·41	3·31	0·66	0·32	0·08	0·22	2·14	0·66
	5	0·44	0·12	0·34	4·01	0·69	0·34	0·07	0·24	2·82	0·66
	6	0·47	0·14	0·23	4·72	0·68	0·28	0·11	0·11	3·37	0·64
	Average	0·47	0·12	0·66	3·21	0·59	0·32	0·08	0·34	2·39	0·59
$N_0P_2K_0$	1	0·55	0·22	1·26	2·20	0·17	0·47	0·18	1·99	2·88	0·15
	2	0·54	0·25	0·83	1·83	0·14	0·49	0·12	1·21	2·01	0·15
	3	0·48	0·18	0·75	2·22	0·24	0·32	0·28	0·28	2·17	0·15
	4	0·51	0·43	0·18	3·29	0·29	0·29	0·38	0·21	3·22	0·29
	Average	0·52	0·27	0·75	2·38	0·21	0·39	0·24	0·92	2·57	0·19
$N_0P_0K_2$	1	..	0·17	0·268	1·29	0·21	0·39	0·15	3·34	1·64	0·17
	2	0·45	0·28	1·90	1·35	0·29	0·33	0·11	2·32	1·34	0·19
	3	0·49	0·25	1·67	1·64	0·35	0·34	0·12	2·23	1·35	0·19
	4	0·44	0·24	1·92	1·50	0·19	0·29	0·14	1·88	1·34	0·19
	Average	0·46	0·23	2·04	1·44	0·26	0·34	0·13	2·44	1·42	0·18

TABLE 4. *Mineral Content of Abaca Pseudostem Samples in Relation to Fertilizer Treatment Applied*

Nutrient element						
Fertilizer treatment	*Part of plant*	N	P	K	Ca	Mg
$N_0P_0K_0$	Flower and fruit	0·88	0·19	3·86	2·20	0·50
	Leaf petioles	0·29	0·15	1·11	1·91	0·51
	Top of stem	0·39	0·17	1·32	1·37	0·37
	2nd metre of stem	0·29	0·14	1·32	0·79	0·27
	1st metre ,,	0·21	0·14	0·76	0·73	0·41
	Base ,,	0·26	0·19	0·47	0·99	0·94
$N_1P_1K_1$	Flower and fruit	0·98	0·18	3·68	2·31	0·46
	Leaf petioles	0·32	0·16	2·47	2·58	0·60
	Top of stem	0·34	0·13	2·96	1·92	0·46
	3rd metre of stem	0·26	0·11	2·30	0·94	0·19
	2nd metre ,,	0·25	0·09	2·14	1·07	0·13
	1st metre ,,	0·22	0·11	1·96	1·21	0·33
	Base ,,	0·27	0·05	1·99	1·38	0·43
$N_2P_2K_2$	Flower and fruit	1·02	0·15	4·08	1·31	0·25
	Leaf petioles	0·47	0·09	3·13	1·00	0·13
	Top of stem	0·38	0·06	2·79	0·71	0·30
	3rd metre of stem	0·34	0·05	2·07	0·73	0·09
	2nd metre ,,	0·33	0·04	2·35	0·08	0·13
	1st metre ,,	0·40	0·04	2·41	1·07	0·14
	Base ,,	0·41	0·04	3·65	0·87	0·24
$N_2P_0K_0$	Flower and fruit	1·36	0·16	3·47	1·67	0·49
	Leaf petioles	0·33	0·07	1·05	1·60	0·44
	Top of stem	0·38	0·08	1·40	0·71	0·30
	3rd metre of stem	0·36	0·05	0·81	0·72	0·32
	2nd metre ,,	0·39	0·06	0·90	1·09	0·59
	1st metre ,,	0·33	0·05	0·42	1·01	0·46
	Base ,,	0·39	0·09	0·47	1·04	0·34
$N_0P_2K_0$	Flower and fruit	1·59	0·45	3·17	3·08	0·37
	Leaf petioles	0·31	0·14	1·39	2·22	0·23
	Top of stem	0·48	0·33	2·68	2·26	0·24
	3rd metre of stem	0·33	0·35	1·41	1·20	0·18
	2nd metre ,,	0·27	0·42	1·17	1·17	0·14
	1st metre ,,	0·23	0·16	0·92	1·69	0·25
	Base ,,	0·36	0·43	1·09	1·87	0·74
$N_0P_0K_2$	Flower and fruit	1·28	0·26	5·25	1·63	0·41
	Leaf petioles	0·29	0·24	4·65	1·09	0·14
	Top of stem	0·27	0·17	3·45	0·74	0·13
	2nd metre of stem	0·22	0·28	2·71	0·93	0·13
	1st metre ,,	0·19	0·26	2·71	1·09	0·17
	Base ,,	0·22	0·22	4·09	0·80	0·24

ESTIMATING THE PROBABLE CHANGE IN YIELD WITH TIME, ON ALTERING THE LEVEL OF MANURING OF TEA

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Summary

The manner in which yields change in the years immediately following an alteration in the level of manuring of unshaded mature tea grown in north-east India has been investigated. Explaining the theoretical basis on which the equation is derived, the author now proposes the general equation $y = A\,(1-e^{-zt-ut^2})$, which is applicable to all types of manures and fertilizers, to estimate the probable change in yield with time when the level of manuring is either increased or decreased in and from a given year. This equation can yield curves of either the 'S' type or of the 'continuously falling' type, depending on the values of the constants z and u. Data from four manurial trials carried out at the Borbhetta field-experimental station for periods varying between six and eleven years are quoted and it is shown that the equation fits the data well ($P < 0{\cdot}01$). The shapes of the yield/time curves are entirely different for cattle manure and for inorganic fertilizer treatments. The physical meaning of the constants is explained and it is shown that the values of the constants are such that an 'S' type of curve is possible only with cattle manure (which has low availability but a high residual effect) treatment, whereas inorganic fertilizers (which have high availability but low or negligible residual effect) give curves of the 'continuously falling' type. The method of obtaining the 'least square' solution is described in an Appendix.

ALTHOUGH numerous attempts [1] have been made in the past to find mathematical expressions for the relationship between the dose of fertilizer applied and the growth of the crop, one other important aspect of the relation between manuring and yield appears to have escaped the attention of any previous worker. This concerns the manner in which yields change in the years immediately following an alteration in the level of manuring. A perennial crop such as tea presents an ideal case for study of this relationship. This question is not only of theoretical but also of some considerable practical importance: tea-garden managements are naturally interested in knowing how yield is likely to be affected in the years immediately following a change in the level of manuring. The only published information on the subject appears to be that by the present author, who in a previous paper [2] described a simple solution which holds good with inorganic fertilizers. A general solution which is valid for all types of manures and fertilizers is now presented.

Changes in yield can result from a variety of causes, and therefore it is necessary to specify certain conditions. Most of the tea in north-east India is pruned annually and the present discussion refers to tea grown there and so treated. Similar considerations may be applicable to tea pruned on longer cycles, but the successive annual yields would, of course, not be comparable with regard to the subject here being studied. With young tea the position is complicated also because the bush changes appreciably in size during this formative period and the yields from

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year to year are therefore similarly not comparable. Manurial responses of shaded tea are also complicated by shade factors, and the discussion that follows is confined to mature and unshaded healthy tea.

Yields can be manipulated by changes in cultural practices, such as altering the time of pruning, changing the tipping height, altering the method and style of plucking, &c. In analysing the effects of manuring, it has to be ensured that these other factors remain unaltered and this condition is satisfied in the examples quoted here.

Variations in climatic conditions from year to year will also be reflected in yields. There is no simple method of correcting for this variation and, in the discussion that follows, consideration is given only to the *differences* in yields with two different manurial treatments and not to their intrinsic values. Variations in climatic conditions from year to year will result merely in random deviations in the levels of the yield figures. It is immaterial what the chosen two manurial treatments are. The change in the level of manuring in and from a given year may consist in starting to manure at a steady level; or ceasing to manure; or merely an increase or decrease in the level of manuring. Although the reasoning is slightly different for increasing and for decreasing the level of manuring, the basic considerations remain the same, and the same mathematical equation is valid in all cases.

With no manuring at all, it is possible to maintain yields of the order of 400–480 lb. of made tea per acre (say Y_0) in the Assam Valley. With manuring the yield can be increased, and it is common experience that with continued manuring, the yield increases gradually and, in course of time, attains a certain optimum value (say Y_n), the net final increase in yield ($Y_n - Y_0 =$ say A) being roughly proportional to the level of manuring, for the levels commonly employed. The problem is to evaluate the nature and the shape of the yield/time curve when the level of manuring is altered in and from a given year. Two basic conditions which must be kept in mind in studying this question mathematically are that the yield difference is 0 when $t = 0$, and that it approaches an equilibrium value in course of time. If y be the difference in yield at any time t, then the rate of change in yield at that time should be proportional to $(A-y)$. It has been shown that with mature tea grown under the conditions obtaining in north-east India, the nutrient of predominant importance is nitrogen, not phosphorus or potassium, and the form in which the nitrogen is supplied may be expected to affect the yield/time curve. The efficiency, and the residual effect in the soil, of the given manure would be important, especially when the effects of cattle manure and inorganic nitrogen are compared. If 'r' is an index of the 'residual effect in the soil' of the given manure then, from first principles, the rate of increase in yield at any time t may be taken as

$$\frac{dy}{dt} \propto (1+rt)(A-y) \tag{1}$$

$$= z(1+rt)(A-y), \tag{2}$$

where z is a constant. Substituting $zr = 2u$, where u is another constant,

equation (2) becomes

$$\frac{dy}{dt} = (z+2ut)(A-y). \tag{3}$$

On rearranging and integration, putting in the boundary condition $y = 0$ when $t = 0$, we arrive at the final equation

$$y = A\,(1-e^{-zt-ut^2}). \tag{4}$$

As explained previously, the above equation is valid when the level of manuring is either increased or decreased, but the significance of the constant z would, of course, be different in the two cases. When increasing the level of manuring, z is an index of the inherent efficiency (i.e. availability) of the manure concerned. When reducing the level, however, z would be an index of the local soil conditions. The significance of the other constants remains unaltered.

It is evident that the shape of the yield/time curve will depend on the relative values of the constants z and u and that the identical equation can produce curves of either the 'continuously falling' type or the 'S' type, depending on the values of these constants. The condition for obtaining an 'S' type of curve is easily calculated from equation (4) by evaluating d^2y/dt^2. The value of t at the point of inflexion is

$$t = \frac{-z \pm \sqrt{2u}}{2u} \tag{5}$$

$$= \frac{-z \pm \sqrt{rz}}{rz}, \tag{6}$$

and ignoring the negative sign of the second term in the numerator,

$$t = \frac{\sqrt{(r/z)}-1}{r}. \tag{7}$$

If the curve is to have a real point of inflexion, then the value of $\sqrt{(r/z)}$ must be greater than unity.

The method of obtaining the 'least square' solution is described in the Appendix. As criterion of goodness of fit, the correlation coefficient (R) equivalent to the multiple correlation coefficient between the observed and computed values as described by Brooks and Carruthers [3] was calculated and was found to be highly significant in all cases ($P < 0{\cdot}01$); the different R values have been quoted in the text. It may be possible to fit other equations which in specific cases would give as good a fit as that obtained with the equation described here. It is to be noted, however, that the identical equation has been fitted by the author to all data, although the nature of the yield/time changes differs so widely with inorganic N.P.K. and with cattle-manure treatments. A solution of universal validity is obviously to be preferred to others which are applicable only in specific instances. Furthermore (in the opinion of the author this is a specially important consideration), the theoretical basis on which the equation is derived has been explained, so that the physical meaning of the constants is clear. It is claimed that the equation described in this paper satisfies these conditions simultaneously and adequately. Data from four trials carried out at the Borbhetta field

experimental station for periods varying between 6 and 11 years are now presented, there being two examples each for cattle manure and inorganic fertilizers.

Example A. Increase in Yield with Continued Application of Cattle Manure; Borbhetta area B 15

Jat[1] of tea Dhoolie, planted in 1928 at 4½ feet triangular spacing, unshaded. The statistical layout was of the randomized block design with sevenfold replication. The area of each plot was 0·036 acres. The manurial treatments were control (continuously unmanured); and annual applications of cattle manure, ammonium sulphate, or five different forms of compost, to supply nitrogen at the rate of 80 lb. per acre in all cases, but data in respect of only the first two named treatments (control and cattle manure) are quoted here. Manurial treatment started in 1936

TABLE 1. *Increase in Yield with Annual Applications of Cattle Manure in Borbhetta Area B 15, unshaded tea*

Manurial treatment		*Yield, maunds* of made tea per acre*						
		1937 (unmanured)	*1938*	*1939*	*1940*	*1941*	*1942*	*1943*
A: Cattle manure		7·91	7·76	7·03	7·58	9·85	11·88	12·46
B: Control (continuously unmanured)		7·09	6·66	5·25	5·05	6·02	6·96	6·99
Least significant difference $P = 0{\cdot}05$		0·42	0·44	0·56	0·69	0·82	1·13	0·61
Increase between treatments A and B	actual	0·82	1·10	1·78	2·53	3·83	4·92	5·47
	calculated	0·82	1·03	1·72	2·71	3·80	4·78	5·55

* 1 maund = approx. 82 lb.

but no manures at all were applied in 1937 and the trial really commenced from 1938, after which manuring was continued annually. The result of this irregularity was that the difference in mean yield in 1937 between the cattle-manure-treated and control plots was 0·82 maunds, although no manures were applied during the whole of 1937. In view of this, 1938 has been taken as the first year of regular manuring, but all yield figures were adjusted for the 1937 difference in yield. The least-square solution for the successive increases in yield with time is:

$$y = 0{\cdot}82 + 5{\cdot}92(1 - e^{+0{\cdot}010t - 0{\cdot}046t^2}) \text{ mds./acre.}$$

Full data for the period 1937–43 appear in Table 1 (see also Fig. 1). The correlation coefficient (R) is 0·9977.

Example B. Increase in Yield with Continued Application of Cattle Manure at Two Levels; Borbhetta area B 39

Jat of tea Tingamira, planted in 1921 at 4½ feet triangular spacing, unshaded. The statistical layout was of the randomized block design with sixfold replication. The area of each plot was 0·036 acres. The

[1] Populations of seed progeny raised from a particular seed bari (orchard) are known collectively as a jat.

manurial treatments were control (continuously unmanured); and cattle manure applied annually at the levels of 5, 10, and 20 tons per acre, but the data for only the 5 and 10 ton levels have been utilized in this investigation. The corresponding average rates of nitrogen application were 75 and 150 lb. per acre. The least-square solution for the difference

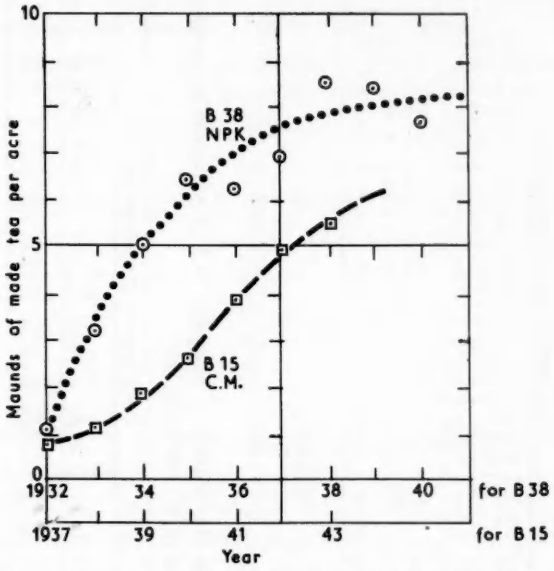

FIG. 1. Increase in yield on starting to manure unshaded tea.

in successive increases in yield with time with the above two treatments is

$$y = 4{\cdot}76(1-e^{-0{\cdot}034t-0{\cdot}018t^2}) \text{ mds./acre.}$$

Full data for the period 1931–41 appear in Table 2 (see also Fig. 2). The correlation coefficient (R) is 0·9563.

Example C. Increase in Yield with Continued Application of Inorganic N.P.K. Mixture; Borbhetta Area B 38

Jat of tea Tingamira, planted in 1921 at 4½ feet triangular spacing, unshaded. The statistical layout was of the randomized block design with sevenfold replication. The area of each plot was 0·036 acres. The manurial treatments were control (continuously unmanured), and annual applications of ammonium sulphate and six other types of fertilizers, but data from only the first two named treatments (control and ammonium sulphate) are quoted here. The level of nitrogen application was 60 lb. per acre. In addition, all manured plots received 30 lb. of P_2O_5 and of K_2O per acre, as superphosphate and potassium sulphate. The manurial treatment started in 1931 but no manures at all were applied in 1932 and the trial really commenced from 1933, after which manuring

TABLE 2. *Increase in Yield with Annual Application of Cattle Manure at two levels in Borbhetta Area B 39, unshaded tea*

Cattle manure treatments		*Yield, maunds of made tea per acre*										
		1931	*1932*	*1933*	*1934*	*1935*	*1936*	*1937*	*1938*	*1939*	*1940*	*1941*
A: 10 tons (approx. 150 lb. N) per acre		10·10	10·60	11·60	12·80	12·80	11·80	12·95	15·44	16·02	13·75	15·10
B: 5 tons (approx. 75 lb. N) per acre		9·60	10·30	10·60	10·30	10·80	9·80	9·86	11·25	11·72	9·62	10·93
Least significant difference $P = 0{\cdot}05$		0·50	0·60	0·70	0·60	0·90	1·00	1·14	0·90	1·14	1·07	0·83
Difference between treatments A and B	actual	0·50	0·30	1·00	2·50	2·00	2·00	3·09	4·19	4·30	4·13	4·17
	calculated	0·24	0·63	1·12	1·66	2·22	2·75	3·23	3·64	3·97	4·22	4·40

TABLE 3. *Increase in Yield with Annual Application of Inorganic N.P.K. Mixture in Borbhetta Area B 38, unshaded tea*

Manurial treatment		*Yield, maunds of made tea per acre*								
		1932 (unmanured)	*1933*	*1934*	*1935*	*1936*	*1937*	*1938*	*1939*	*1940*
A: N.P.K. mixture (from 1933 onwards)		8·94	12·31	11·61	12·41	12·20	12·70	14·25	13·89	12·69
B: Control (continuously unmanured)		7·91	9·12	6·58	5·98	6·00	5·82	5·71	5·51	5·08
Least significant difference $P = 0{\cdot}05$		0·57	0·62	0·64	0·62	0·66	0·79	0·98	0·94	1·00
Difference between treatments A and B	actual	1·03	3·19	5·03	6·43	6·20	6·88	8·54	8·38	7·61
	calculated	1·03	3·29	4·90	6·04	6·83	7·37	7·73	7·97	8·13

was continued annually. The result of this irregularity was that the difference in yield in 1932 between the N.P.K. and control plots was 1·03 maunds per acre, although no fertilizer was applied during 1932. In view of this, 1933 has been taken as the first year of regular manuring, but all yield figures were adjusted for the 1932 difference in yield. The least-square solution for the successive increases in yield with time is

$$y = 1{\cdot}03 + 7{\cdot}36(1 - e^{-0{\cdot}359t - 0{\cdot}007t^2}) \text{ mds./acre.}$$

Full data for the period 1932–40 appear in Table 3 (see also Fig. 1). The correlation coefficient (R) is 0·9563.

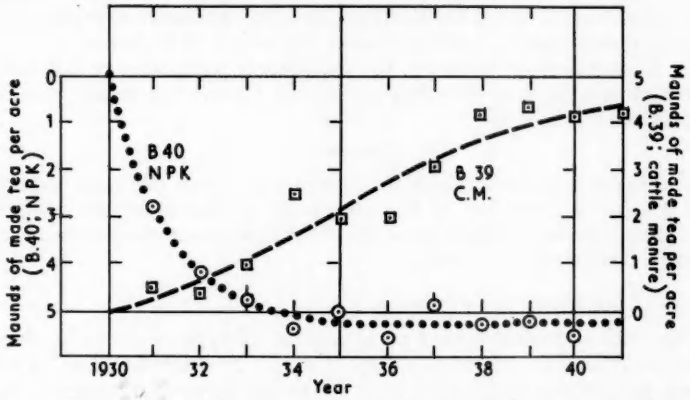

FIG. 2. Differences in yield on starting to and ceasing to manure unshaded tea.

Example D. Difference in Yield between Manured (Inorganic N.P.K. Mixture) and Control Plots, Borbhetta Area B 40

Jat of tea Tingamira, planted in 1921 at 4½ feet triangular spacing, and unshaded throughout the period here under discussion. The statistical layout was of the randomized block design, with eightfold replication. The area of each plot was 0·036 acres. The manurial treatments were control (continuously unmanured); and fifteen different combinations of N.P.K. application, nitrogen as ammonium sulphate applied in all years except 1933 and 1936 when calcium cyanamide was substituted, at 40 lb. nitrogen per acre, and phosphate/potash in the form of superphosphate and potassium sulphate at various rates between 0 and 60 lb. per acre, but data in respect of only two treatments, i.e. control and $N:P_2O_5:K_2O$ application at the level 40:30:15 lb. per acre, are quoted here. The initial fertility of the plots was high and it will be seen from the figures quoted that the yield was barely maintained even with 40:30:15 manuring. In 1931 the yield of the manured plots was 13·53 maunds per acre, and not only was this not exceeded during the succeeding nine years but it actually dropped slightly. The control plots, on the other hand, dropped in yield considerably more. A comparison of these two treatments is, therefore, really a measure of the

effect of ceasing to manure under these conditions. The least-square solution for the successive differences in yield with time is

$$y = 5{\cdot}24(1-e^{-0{\cdot}646t-0{\cdot}069t^2}) \text{ mds./acre.}$$

Full data for the years 1931–40 appear in Table 4 (see also Fig. 2).

The correlation coefficient (R) is 0·9672. For reasons which have already been explained, the value of the constant z in this instance is an index of the soil conditions and not of the efficiency of the fertilizer. It is interesting to note that the present calculation is in substantial agreement with data presented in the earlier paper [2]; the simple solution proposed then was $y = A(1-e^{-kt})$, and using data from two entirely separate field trials carried out at Borbhetta on ceasing to manure covering a period of only three years in each instance, the value of k derived was about 0·81. In the present instance, the expression equivalent to k is $(z+ut)$, and the mean value of the latter expression for the first three years of the trial works out to 0·78.

Conclusions

The following conclusions may be drawn from the data presented. The results obtained are, in all cases, fully in conformity with what one may expect from fundamental considerations about the nature of cattle manure and inorganic fertilizers.

Shape of the Yield/Time Curve

The critical condition[1] for obtaining an 'S' type of curve is given by equation (7) and the different values of $\sqrt{(r/z)}$ are quoted in Table 5; these values are greater than unity only for cattle manure treatment. It can be seen, therefore, that the values of the constants z and u are such that an 'S' type of curve is possible only with cattle-manure treatment, whereas inorganic fertilizers give curves of the 'continuously falling' type.

The Value of Time t at the Point of Inflexion

The calculated values are quoted in Table 5. It is interesting to note that, under the soil and climatic conditions obtaining at Borbhetta (which are typical of a large portion of the tea areas of north-east India), the building-up process with continuous cattle manure treatment goes on for about three to four years, which is apparently the maximum time for which the residual effect of a particular cattle manure application can persist in the soil. In the case of inorganic fertilizers, the calculated values of t are negative, indicating that there is no point of inflexion in their case.

Inherent Efficiency or Availability (E_0)

This is given by the constant z in the case of the first three quoted examples. The respective values are presented in Table 5 and it is seen that the availability of cattle manure is very low (in the case of Example A,

[1] If z is negative (as in Example A) there is always a point of inflexion, irrespective of the magnitudes of z and u.

TABLE 4. *Differences in Yield between Manured (Inorganic N.P.K. Mixture) and Control Plots in Borbhetta Area B 40, unshaded tea*

Manurial treatment, applied annually		*Yield, maunds of made tea per acre*								
		1931	*1932*	*1933*	*1934*	*1935*	*1936*	*1937*	*1938*	*1939*	*1940*
A: N.P.K. mixture		13·53	12·85	13·34	13·52	12·74	11·88	11·41	12·54	11·94	11·38
B: Control (continuously unmanured)		10·86	8·67	8·60	8·24	7·77	6·31	6·55	7·32	6·77	5·88
Least significant difference $P = 0·05$		0·54	0·63	0·70	0·88	0·91	1·10	0·83	0·93	0·78	0·87
Difference between treatments A and B	actual	2·67	4·18	4·74	5·28	4·97	5·57	4·86	5·22	5·17	5·50
	calculated	2·68	4·15	4·83	5·11	5·20	5·23	5·24	5·24	5·24	5·24

TABLE 5. *Summary of Results from Four Borbhetta Manurial Trials*

Type of manure applied	*Field trial in Borbhetta area*	*Levels of manuring compared*	*Data available for years*	$\sqrt{(r/z)}$	*Shape of yield/time curve*	*Value of t at point of inflexion*	$E_0 = z$ *Inherent efficiency or availability*	$r = 2u/z$ *Residual effect in the soil*	E_∞ *Final efficiency, lb. made tea per lb. N*
Organic; cattle manure	B 15	Control (continuously unmanured), and cattle manure to supply 80 lb. nitrogen per acre per year	6	30·3*	'S' type	3·4 years	$-0{\cdot}01_0$	9·2	6·1
	B 39	Cattle manure at two levels, to supply 75 and 150 lb. nitrogen per acre per year	11	5·6	,,	4·3 years	$+0{\cdot}03_4$	1·1	5·2
Inorganic; N.P.K. mixture	B 38	Control (continuously unmanured), and $N:P_2O_5:K_2O$::60:30:30 lb. per acre per year	8	0·3	'continuously falling' type	negative value (i.e. no point of inflexion)	$+0{\cdot}35_9$	$0{\cdot}0_4$	10·1
	B 40	Control (continuously unmanured), and $N:P_2O_5:K_2O$::40:30:15 lb. per acre per year	10	0·6	,,	,,	not applicable	0·2	10·7

* Value of z being negative, there is a point of inflexion irrespective of this value.

the value is actually negative), whereas a much higher figure is evident in the case of an inorganic fertilizer such as ammonium sulphate.

Residual Effect in the Soil

This is indicated by 'r' which is equal to $2u/z$ and the calculated values are quoted in Table 5. With the inorganic fertilizer, the 'r' values are small fractions, whereas much higher values are obtained with cattle manure, indicating a pronounced residual effect of the latter. There is also some indication that with cattle manure the 'r' value falls off with the level of application.

Final Efficiency (E_∞)

Because of the difference in the shapes of the yield/time curves, the final efficiency (i.e. the value when yield attains the equilibrium level) of different manures is not the same as what has previously been referred to as 'Inherent efficiency or availability'. The final efficiency (E_∞) is calculated from the constant A after adjusting for the rate of manuring. The values obtained in the four field trials, on equivalent nitrogen basis, are presented in Table 5. In unshaded tea, the average value of (E_∞) for cattle manure is about 54 per cent. of that for the inorganic fertilizer mixture containing ammonium sulphate, a result which is in agreement with previous data. The (E_∞) value appears to show a slight falling off with higher levels of manuring.

Acknowledgement. The author is grateful to the Indian Tea Association for permission to publish these results.

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APPENDIX

Method of Obtaining the 'Least square' Solution for the Equation $y = A(1-e^{-zt-ut^2})$

If q and y be the observed and computed values, respectively, and v the corresponding 'residual', then the problem is to make

$$\sum(v^2) = \sum\{q-(A-Ae^{-Zt-Ut^2})\}^2$$

minimum, by suitable choice of the constants A, Z, and U. The general method of simplifying such complex problems is to write

$$A = a_0+a, \qquad Z = z_0+z, \qquad U = u_0+u,$$

where a_0, z_0, and u_0 are approximate solutions of the required constants and the values of a, z, and u are to be so small that they can be treated as small increments. Now we know that

$$d(A-Ae^{-Zt-Ut^2}) = dA-dA(e^{-Zt-Ut^2})+Ate^{-Zt-Ut^2}\,dZ+At^2e^{-Zt-Ut^2}\,dU. \quad \text{(i)}$$

If we substitute $dA = a$, $dZ = z$, and $dU = u$, then in the approximate solution, the right-hand side of equation (i) becomes

$$= (1-e^{-z_0t-u_0t^2})(a)+(a_0te^{-z_0t-u_0t^2})(z)+(a_0t^2e^{-z_0t-u_0t^2})(u), \quad \text{(ii)}$$

$$\equiv \text{let } S. \quad \text{(iii)}$$

Now, $$(a_0+a)[1-e^{-(z_0+z)t-(u_0+u)t^2}] = a_0(1-e^{-z_0t-u_0t^2})+S, \quad \text{(iv)}$$

and the residual v is given by

$$v = q-a_0(1-e^{-z_0t-u_0t^2})-S, \quad \text{(v)}$$

which is of the form, $$v = k+la+mz+nu, \quad \text{(vi)}$$

where k, l, m, and n are numerical coefficients.

By substituting proper coefficients, one obtains as many equations of type (vi) as there are observed points. In order to make $\sum(v^2)$ minimum, the three normal equations are then worked out in the usual manner and the values of the corrections a, z, and u calculated.

Unfortunately a difficulty in this case is that, due to the complex nature of the equation, there is no mathematical procedure for evaluating the approximate value of the constant A. The only course left is to assume an arbitrary value (the points are plotted and an estimate then made) for a_0, obtain the best estimates of the constants z_0 and u_0 (this is easily done, remembering that $\log(1-q/a_0) = -z_0t\log e-u_0t^2\log e$, the least square values of z_0 and u_0 being obtained in the usual manner), and then proceed to calculate the corrections a, z, and u. If it is found that the value of any of these is high, then the approximate value chosen is discarded (as in that case equation (iv) is no longer valid) and a fresh start has to be made with another value. This process is continued until it is found that the first corrections obtained are in fact small. Although this operation may sometimes turn out to be tedious, with a little practice and by means of extrapolation one can arrive at the right value without undue difficulty.

Once a satisfactory approximate solution is obtained, all that remains to be done is to arrive at the final answer by the method of successive approximation. The author found that usually three, or at the most four, cycles of successive calculations were enough to arrive at the final desired answer, which is the 'least square' solution. At each successive calculation, the value of $\sum(v^2)$ diminishes until it reaches the minimum, and by the third or fourth cycle the corrections are reduced to negligible quantities.

CACAO YIELD MAPS AND SOIL FERTILITY IN GHANA

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Summary

A technique is described for producing cacao yield contour maps. Yields on a soil developed under moist semi-deciduous forest in Ghana[1] were shown to be correlated with the chemical analysis of the 0–6 in. layer of the soil. The yield pattern revealed by these contours indicated a local high variability in the fertility of the surface horizon of the soil.

A HUMID tropical climate and its associated forest give rise to soils which are extremely variable in their surface horizons. The work of Jenny *et al.* [3] in Columbia illustrates the large variability of forest floor litter, which probably results from a localized heterogenity of the tree population similar to that mentioned by Foggie [2] in his description of the forest of Ghana. This litter is obviously a major factor in the formation of the variable surface horizons of these forest soils.

The root systems of many forest trees in Ghana are found mainly within 3 feet of the soil surface, as fully described by Foggie [2]. Cacao, which is the predominant tree crop grown within the Ghanaian forest, also has a very shallow root system and some 85 per cent. (by weight) of the cacao roots is frequently found within 6 inches of the soil surface. This shallow-rooting habit emphasizes that the growth of both forest trees and cacao may be greatly influenced by variations in fertility of the surface horizons of the soil.

Since the beginning of this century, the native farmer has developed the largest cacao industry in the world within the 30,000 square miles of the Ghanaian forest. This cacao is irregularly planted and grown under the variable shade provided by the partly cleared forest. Until quite recently, cacao scientific research in Ghana has been mainly concerned with the control of pests and diseases. These not only seriously threatened the crop but rendered unreliable any estimations of soil productivity based on cacao yields. Except for the pioneer work of Hardy *et al.* [4, 5], who attempted to correlate laboratory analyses of soils with cacao yields, and Charter [6] and Brammer [7], who conducted soil surveys, soil studies in the Ghanaian forest have not been extensive.

The introduction of adequate pest and disease control measures and more uniform cultivation methods in recent years have together produced more reliable cacao yield data. These data have enabled more accurate comparisons to be made of the productivities of different sites, but have also revealed the highly localized yield variability which can occur at any one site.

In this paper yield maps of a 10-acre site planted uniformly with cacao

[1] For descriptions of forest type see Taylor [1] and Foggie [2].

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are presented, and illustrate the extent of this local variability. These maps were constructed using a technique similar to one that Fairfield Smith [8] used with wheat. The possibility that the yield pattern revealed by these maps might be related to the nutrient contents of the surface horizons of the soil was investigated.

Materials and Methods

Cacao Material

A 10-acre uniformity trial was planted in 1947 at the West African Cocoa Research Institute, Tafo, Ghana. This trial contained approximately 6,000 Amelonado cacao trees planted as seed on the square in straight lines at 8×8 ft. spacing and under uniform shade. The site chosen was quite flat, was not intersected by streams, and was devoid of both termitaria and rock outcrops. A few giant forest trees which had fallen many years previously provided the only obvious surface non-uniformity. Furthermore, the whole trial was sited on a single soil series (W.A.C.R.I. series) which is classified by Brammer [7] as one of the best cacao soils in Ghana. Records were kept of the number of pods harvested from every individual tree, some of which began bearing in 1953.

Map Construction

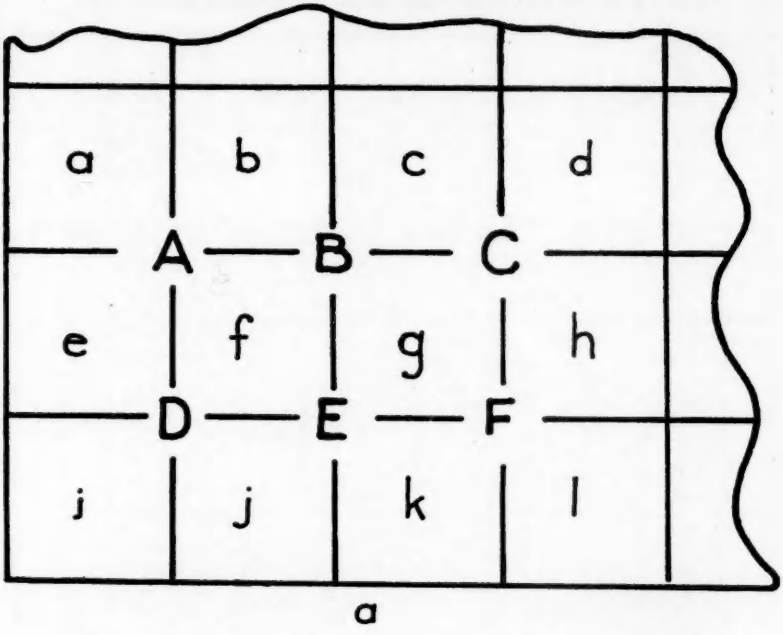
Since the yields of cacao are particularly variable in their first years of bearing, use was not made of data obtained prior to 1956. Yield maps were constructed for the two seasons 1956–7 and 1957–8 by the following method which is very suitable for use with regularly planted trees.

The 10-acre site was divided into small square plots whose positions were marked on a plan of the site, of which a small section is shown in Fig. 1. The total yield of every four adjacent plots was marked on the plan at their common corner. For example, the combined yield of plots *a*, *b*, *e*, and *f* was entered at *A* on the plan, as shown in Fig. 1*a*. Similarly, the combined yield of plots *b*, *c*, *f*, and *g* was plotted at *B*. Yield values were plotted over the whole plan of the site at such points, *A*, *B*, *C*, ... Linear interpolations of numerically convenient yield values were made on the lines joining adjacent points *A*, *B*, *C*, ... as illustrated by the hypothetical values shown in Fig. 1*b*. Yield contours were subsequently drawn over the plan by connecting appropriate yield values.

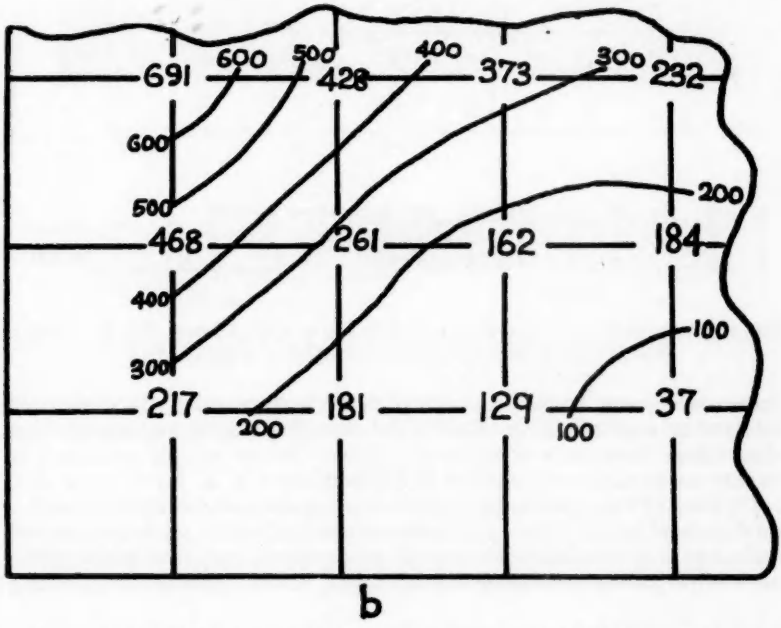
Different maps were constructed by using small plots (*a*, *b*, *c*, ...) which contained 1, 9, 25, or 100 trees. The values plotted at *A*, *B*, *C*, ... therefore represented the yields from the surrounding 4, 36, 100, or 400 trees. A small unit plot containing 25 trees gave the most satisfactory pattern and was adopted for the fertility investigation. The whole site was divided into 256 units of this size. Units containing less than 25 trees gave very complex yield patterns, whereas the yield pattern constructed from 100-tree units was over-simplified.

Soil Sampling and Analysis

From the maps constructed as described above, areas of low, medium, and high yield were chosen within the 10-acre trial. Within each of



a



b

FIG. 1. Diagrams illustrating method of constructing cacao yield maps (see text).

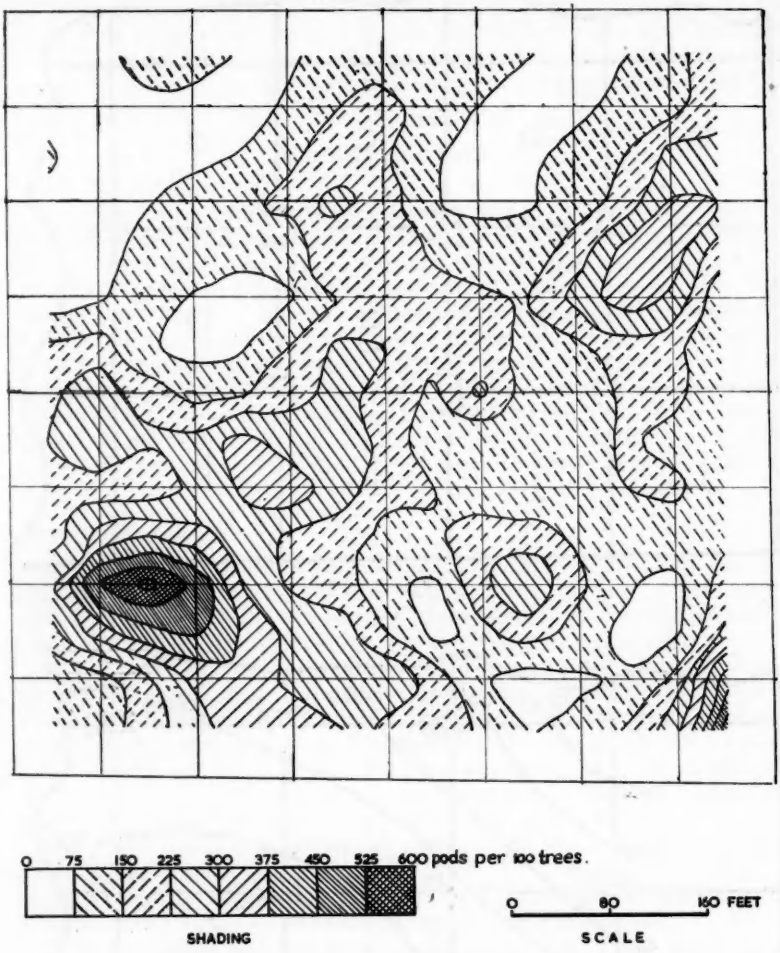


FIG. 2. Cacao yield contour map of a 10-acre site at Tafo, Ghana. Based on individual records from 6,000 Amelonado trees for season 1956–7.

these yield areas, three 0·15-acre plots each containing 100 trees were selected as representative of the yield classification. A soil sample was then taken from each of these nine plots. Every sample consisted of twenty cores taken with a screw auger from the 0–6 in. layer of the soil.

On each of these soil samples the following determinations were made: total carbon [9], total nitrogen (semi-micro Kjeldahl), pH (water-to-soil ratio 2·5:1, glass electrode), organic phosphorus [10], 'available' phosphorus [11], base exchange capacity [12], exchangeable calcium and

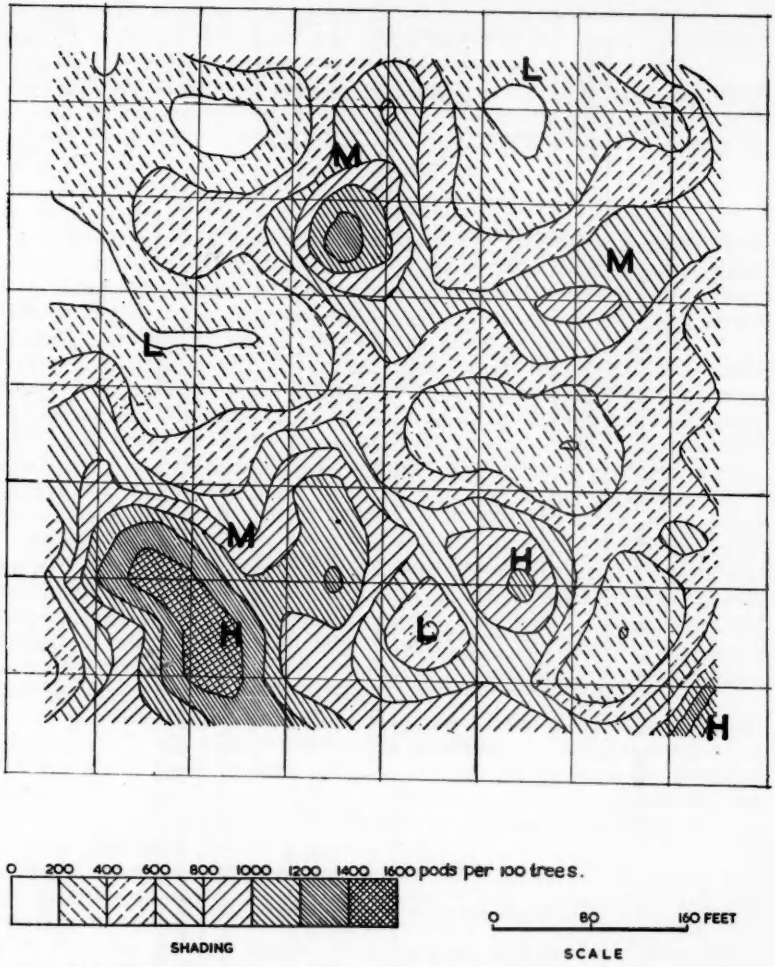


FIG. 3. Cacao yield contour map of a 10-acre site at Tafo, Ghana. Based on individual records from 6,000 Amelonado trees for season 1957–8.

magnesium [13, 14], exchangeable potassium (EEL flame photometer), acid soluble potassium [15], and mineralization of nitrogen [16, 17].

Results

Cacao yield contour maps for the two seasons 1956–7 and 1957–8 were constructed in the manner described, and are shown in Figs. 2 and 3. The contours shown in these maps represent the number of pods harvested per 100 trees. These maps demonstrate clearly that, within this

TABLE 1. *Chemical Analysis* of Air-dried Soil from 0–6 in. Layer*

Yield grading according to maps	*Actual yield per 100 trees†*	*Total carbon* C	*Total nitrogen* N	C/N *ratio*	pH	*Organic phosphorus* P	*'Available' phosphorus* P	*Base exchange capacity*	*Exchangeable bases* Ca	Mg	K	*1·0 N. nitric acid soluble potassium* K	*Mineralizable nitrogen‡* NH_4–N	NO_3–N	*Total mineral* N
	pods	%	%			p.p.m.	p.p.m.	m.e./100 g.	m.e./100 g.	m.e./100 g.	m.e./100 g.	m.e./100 g.	p.p.m.	p.p.m.	p.p.m.
Low	86	1·70	0·156	10·90	6·1	310	5	13·7	9·46	2·14	0·29	1·10	+14	+23	+37
Medium	297	1·82	0·170	10·71	6·8	331	7	15·7	12·71	1·58	0·29	0·81	+ 3	+31	+34
High	504	2·10	0·187	11·22	6·9	379	10	18·2	18·45§	1·61	0·38	2·07	+ 1	+30	+31

* All values are means of three samples, each consisting of twenty cores.
† Mean of two seasons, 1956–7 and 1957–8.
‡ Air-dried soil incubated for 14 days at 25° C. and at 50 per cent. of moisture-holding capacity.
§ High exchangeable calcium due to presence of small quantities of free $CaCO_3$.

site, plots of 100 trees may vary eightfold in their yields. The contour patterns obtained in these two successive seasons were strikingly similar.

The surface horizon of the soil was sampled after the 1957–8 season in plots which are indicated in Fig. 3. The mean values of the soil analyses from the low-, medium-, and high-yield areas are shown in Table 1.

Discussion

The mapping technique used at this site has revealed a definite yield pattern with a local high variability. This pattern might be the result of the single or combined effects of planting and establishment, non-uniform shade, irregular topography, genetic variations in the cacao material, the distribution of pests and diseases, or soil factors.

The further possibility that the yield pattern was seasonal is considered most unlikely since the pattern was repeated in different years. The greatest care was taken to ensure uniform planting, establishment, and shading and it is therefore also extremely improbable that the pattern was due to any of these factors. Topographic features cannot account for the pattern since the area was specifically chosen because of a uniformity which was unusual under Ghanaian forest conditions. A genetic explanation of the pattern is unlikely when it is considered that effective randomization of seed must have occurred at planting, that every map contour is based on the combined yield of 100 trees and that Amelonado cacao provides the most genetically uniform seed in Ghana. It also seems reasonable to disregard the possible effects of pests and diseases since control measures at this site have maintained their incidence at an extremely low level.

Soil factors remain a possible explanation of the yield pattern. Figs. 2 and 3 and Table 1 show that yields are definitely correlated with the nutrient status of the 0–6 in. layer of the soil, as assessed by chemical analysis. Because of this correlation it is reasonable to conclude that the yield pattern shown in these Figures is a reflection of fertility variations in the surface soil.

Two interesting features of the chemical analysis of the soil at this site deserve comment. First, the remarkably low 'available' phosphorus which is typical of the Ghanaian forest soils [18, 19], and second, the noticeably better base status of the soil in the high-yielding areas, particularly the potassium reserves as estimated by nitric acid extraction, and the exchangeable calcium.

In Ghana all methods of soil sampling and field experimentation within the forest should take into account the very localized variations in fertility of the surface horizons which have been shown to occur within a single soil series. In view of this variability, widely scattered profile pits may be sufficient for the general classification of these soils, but are of limited value for detailed fertility studies. A sampling rate of forty cores per acre, which has been suggested provisionally for use in Ghana, is probably inadequate for nutritional advisory work. A higher density of sampling must be used if such advisory work is based on

chemical analysis of the soil, and the rate used in this study, approximately 150 cores per acre, appears to be more satisfactory. Results from some field experiments in the forest, especially with cacao, have in the past been contradictory and misleading. One contributory cause for this is undoubtedly the failure of experimental designs to take sufficient account of the local high variability of the soil.

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FERTILIZERS, MANURE, AND MULCH IN KENYA COFFEE GROWING

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Summary

Results obtained since 1947 are presented, from field trials and laboratory studies carried out in Kenya to investigate responses of coffee to fertilizers, manure, and mulch.

It is shown that economic yield increases were obtained to applications of nitrogen fertilizers, grass mulch, and to cattle manure in certain circumstances.

SINCE its introduction to Kenya sixty years ago it has been shown that coffee (*Coffea arabica*) will grow successfully on soils which are free-draining, well aerated, and have a minimum depth of 5 to 8 feet. The trials reported here were located east of the Rift Valley, on unshaded coffee growing on the Kikuyu red or dark-red loam soil, a lateritic clay developed by the leaching of sheet lava. The rainfall distribution follows the monsoon pattern, with two wet seasons which are known locally as Long Rains (late March to early June) and Short Rains (late October to mid-December). A brief outline only is given here since more detailed descriptions of soil and climate are available [1, 2]. Such conditions are typical of the main coffee-producing areas, where the mean annual rainfall is less than 40 inches and may not total 30 inches in a dry year: the ability of the trees to grow and produce a crop is due to the combination of a dense surface root mat and a well-developed deep vertical root system in a fertile soil of high water-holding capacity.

The last comprehensive account describing field responses of Kenya coffee to fertilizers, manures, and mulches, in terms of yield and over-bearing die-back, was published in 1954 [3]. It was deduced from those investigations that organic matter should be applied directly to coffee plantations as a surface protection in the form of grass mulch, rather than be converted to manure and dug into the surface soil. It was found, and since confirmed in greater detail, that the nutrients supplied in grass mulch are considerable and exceed those removed annually in the coffee crop. But under sub-optimal rainfall, soil moisture was the dominant limiting factor, and the special benefits of mulching were attributed to its moisture-conservation effects which had already been established [4]. Responses to dressings of good farmyard manure were found to be generally uneconomic. Thus in principle there was evidence that nutrients could be supplied through the grass which was itself kept at maximum productivity by direct fertilizer applications.

Mature trees failed to respond to phosphorus fertilizers although the available phosphorus in a range of coffee soils was invariably at very low

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levels in all parts of the profile except the top soil. A higher phosphorus content in the foliage of treated trees, without subsequent yield response, indicated that the mature tree was able to absorb its full phosphorus requirements from soil not treated with fertilizer. The concept cannot be extended to young trees with a restricted root range.

It was established, however, that addition of fertilizer nitrogen to supplement the seasonal flush of natural soil nitrogen could lead to benefits in higher yields and better condition of the trees following crop. Study of the relationships between these factors indicated a negative interaction of mulch and nitrogen, particularly under abnormally wet conditions [4, 5].

In the intervening five years these investigations have continued and have been supplemented by further and more intense study, in field and laboratory, of the problems of soil fertility. This paper reports the progress of these studies, from which it is manifest that the evidence differs in some respects and leads to a different interpretation from that derived five years ago.

Phosphorus Fertilizers

In numerous fertilizer trials carried out on coffee in Kenya during the past thirty-four years, the application of phosphates in various forms and at rates between 15 and 42 lb. of phosphorus per acre has failed to produce any significant increase in the yield of coffee. Results of trials carried out on a variety of coffee soils up to 1952 have been fully reported [4], and since that time only one field trial has been continued on the Coffee Research Station.

TABLE 1. *Phosphorus Fertilizers 1950–8*

(*Mean annual yields in cwt. clean coffee per acre*)

Annual application per acre	*Yields*		*Overall means*
	1950–6	*1957–8*	
Control	7·44	13·54	8·79
1950–6: 2 cwt. 'double' superphosphate	7·14	..	8·54
1957–8: 654 lb. basic slag	..	13·42	
	No significant difference		

This trial was laid down in 1950 to test the effect on the yield of coffee of high applications of cattle manure as well as nitrogen and phosphorus fertilizers. During the period 1950–6, 'double' superphosphate was applied at the rate of 2 cwt. (42 lb. phosphorus) per acre each year shortly before the Long Rains. Because this treatment failed to affect either the yield of coffee significantly in any single year or the total yields for the seven years, the form of fertilizer was changed in 1957. In place of 2 cwt. per acre of 'double' superphosphate, basic slag was applied at a rate sufficient to supply the same quantity of phosphorus. Since this alteration of the treatment two crops have been harvested,

but in neither has there been a significant response to the amended treatment. There were no significant interactions of phosphorus with cattle manure or nitrogen in this trial.

Investigations have been carried out from time to time to determine if the applied phosphorus is taken up by the coffee tree. Four months after the basic slag treatment had been applied in 1957, leaf samples (first pair of fully hardened leaves on bearing branches) were collected and analysed for their phosphorus content. In November 1958 a comprehensive programme of soil sampling was carried out in the trial plots and both chemical and biological analyses made (A. Mehlich, unpublished methods). The results of these investigations are summarized in Table 2.

TABLE 2. *Leaf and Soil Phosphorus Values*

Treatment annually[1]	*Leaf phosphorus, % dry matter*	*Soil phosphorus, p.p.m. air dry soil*
Control	0·108	15·2
N	0·113	11·8
P	0·118	16·0
C	0·120	21·0
NP	0·109	14·5
NC	0·121	14·4
PC	0·116	30·2
NPC	0·117	29·6
	N.S.[2]	L.S.D.[2]
		7·1*
		9·5†
Overall treatment effects		
P	N.S.	+ 6·9†
C		+ 9·5†
PC		+ 5·3†
		L.S.D.
		4·8†

[1] N = 92 lb. nitrogen per acre.
P = 42 lb. phosphorus per acre.
C = 4 tins (= 2 bushels) of cattle manure per tree (= about 14–20 tons per acre).

[2] The following abbreviations or symbols are used in this and subsequent tables:
L.S.D. = Least significant difference. N.S. = Not statistically significant.
* = Significant at $P = 0{\cdot}05$. † = Significant at $P = 0{\cdot}01$.
‡ = Significant at $P = 0{\cdot}001$.

The leaf samples collected in August 1957 did not reveal a significant increase in the concentration of leaf phosphorus following the application of phosphorus fertilizers for eight years. Nevertheless, the overall phosphorus fertilizer effect in the soil has been to raise significantly the level of extractable soil phosphorus ($HCl—H_2SO_4$ extraction technique developed by A. Mehlich for the study of Kenya soils). The cattle-manure treatment raised the level of extractable soil phosphorus significantly and the two treatments showed a positive interaction. Overall

mean crop-yield effects for the phosphorus (P) treatments have shown no significant differences (Table 1), neither have the cattle manure (C) or (PC) treatments influenced crop yields significantly in this trial. Comparison of these soil phosphorus values with results of routine soil analyses carried out early in 1959 shows these figures to be within average range of values encountered on estates except for the (C), (PC), and (NPC) treatment figures which are high.

Nitrogen Fertilizers

Several field trials carried out before 1952, and evidence from the chemical analysis of coffee leaves, have made it clear that of all the common nutrient additions the most valuable responses might be expected from nitrogen fertilizers.

Since the first fertilizer trial was laid down on the Coffee Research Station in 1947, several experiments have been initiated to investigate the following main problems:

Quantity of Nitrogen per acre

By 1952 it had become clear that an annual application of 46 lb. of nitrogen per acre represented the lowest rate at which a consistent response was found [4]. A number of new trials were therefore commenced about that time to test higher rates.

TABLE 3. *Yield Responses to the Application of Nitrogen Fertilizers (Ammonium Form)*

Mean annual yields in clean coffee per acre. Mean responses in parentheses

Trial period		No. of seasons	Annual application of nitrogen in lb. per acre					
			0	23	46	69	92	138
			(a) On deep fertile soil					
Ia	1947–56	10	5·57	6·29 (+0·72)*	..	..	..	..
Ib	1947–58	12	6·56	..	7·86 (+1·30)‡	..	..	..
II	1950–8	9	7·71	..	..	..	9·46 (+1·75)‡	..
III	1953–8	6	8·92	..	10·02 (+1·10)*	..	10·37 (+1·45)†	..
IV	1954–8	5	9·47	..	..	10·19 (+0·72) N.S.	..	10·82 (+1·35) N.S.
Weighted percentage response				+12·9%	+16·9%	+7·7%	+19·9%	+14·3%
			(b) On an eroded slope					
Va	1951–3	3	4·21	4·90 (+0·69) N.S.	..			
Vb	1954–8	5	8·04	..	9·42 (+1·38) N.S.			

The yield responses summarized in Table 3 do not reveal any very clear relationship between the rate of nitrogen per acre and the yield of

clean coffee, but except in two of the trials there has been a statistically significant positive response. From these figures it would appear that 46 lb. of nitrogen per acre is the highest rate it is worth distributing in one application, and there is evidence that responses to nitrogen dressings are similar on eroded or fertile soils.

Although there is no doubt that nitrogen fertilizers can raise the mean annual yield over a number of years, this does not necessarily apply to each individual season. For example, in the fertilizer trial which was first recorded in 1947 (Ib), the higher rate of nitrogen fertilizer (46 lb. nitrogen/acre/year) has raised the yields of clean coffee significantly only in five out of the twelve years this trial has been recorded; but in the total yields for the whole period this has amounted to a mean increase in crop of 19·8 per cent., i.e. 1·30 cwt. of clean coffee per acre per year.

Form of Nitrogen Fertilizer

Up to 1951 ammonium sulphate was the only nitrogen fertilizer freely available to the coffee industry and for this reason it was the principal form used in the trials on the Coffee Research Station. In that year a trial was commenced to compare the efficiency of fertilizers containing nitrogen in the ammonium or in the nitrate form. As a third treatment both forms were applied together at the same total rate of nitrogen per acre.

For three years the fertilizers were applied in each April at rates supplying 23 lb. of nitrogen per acre, but in 1954 the rate was doubled.

TABLE 4. *Form of Nitrogen Fertilizer*

Mean annual yields in cwt. clean coffee per acre. Responses % in parentheses

Form of nitrogen	*Rate of fertilizer applied annually per acre*				*1951–8 yield*
	1951–3: 23 lb. nitrogen		*1954–8: 46 lb. nitrogen*		
	Fertilizer	*Yield*	*Fertilizer*	*Yield*	
Nil	..	4·21	..	8·04	6·60
Ammonium	Ammonium sulphate	4·90 (+16·4%) N.S.	Ammonium sulphate 1954–6	9·42 (+17·2%) N.S.	7·72 (+17·0%) N.S.
½ Ammonium, ½ Nitrate	Nitrochalk	5·04 (+19·7%) N.S.	Sodium nitrate and ammonium sulphate 1954–6, or urea 1957–8	9·99 (+19·7%) N.S.	8·12 (+23·0%) N.S.
Nitrate	Sodium nitrate	6·26 (+48·7%)*	Sodium nitrate	10.83 (+34·7%)†	9·12 (+38·2%)†

In both phases of this trial only the nitrogen applied wholly in the nitrate form has raised the yield of coffee significantly.

In 1957 urea became available on the local market at a price cheaper per unit of nitrogen than any other fertilizer, and since it had been demonstrated that repeated heavy applications of ammonium sulphate increased top-soil acidity [6], urea was used thereafter to supply the nitrogen in most of the fertilizer trials on the Coffee Research Station.

Two trials, however, were retained in which urea was compared with ammonium sulphate in the one case and with sodium nitrate and ammonium sulphate nitrate in the other. There are not yet sufficient data available from these trials to make valid comparisons between these several forms of nitrogen fertilizer although there is a suggestion that urea is less efficient than sulphate of ammonia on the basis of equivalent rates of nitrogen [7].

Time of Application

In general the nitrogen fertilizers have been applied shortly after the beginning of the Long Rains.

Studies of the natural inorganic nitrogen trends in a coffee soil, as related to the Rains, the growth periods of coffee, and the modifying influence of the presence of mulches, support the belief that it is desirable to give heavier applications of nitrogen in two parts during the Long Rains period, in order to maintain a reasonable level of nitrate nitrogen in the soil throughout the entire period (April to early June) [8, 9]. Nitrogen fertilizer application is necessary in the early part of the Long Rains because, following a marked initial flush at the onset of the Rains, nitrate values in the soil rapidly fall to a very low and steady level at a time when the growth surge is at its maximum. The second half of the dressing is applied about four weeks after the first, and this is the only treatment which has been shown definitely to modify the shape of the growth curve.

In order to study this problem further in relation to the two distinct rain seasons, a trial was commenced in 1952 to compare equal rates of nitrogen applied early in the Long Rains (April) or early in the Short Rains (November), and a third treatment in which the same total quantities were applied, but half at each season. The total annual rates of nitrogen tested were 0, 46, and 92 lb. per acre.

TABLE 5. *Time of Nitrogen Fertilizer Application*

Mean annual yields in cwt. clean coffee per acre. Responses % in parentheses

Time of fertilizer application	*Yield 1953–8*
Control	8·92
Means of treatments supplying 46 and 92 lb. nitrogen per acre	
Early Long Rains—April	10·14 (+13·7%)*
Early Short Rains—November	10·11 (+13·3%)*
Half in each Rains	10·34 (+15·9%)†

In none of the six crops recorded was there a significant difference between the times of application, though there was usually a tendency for the split application to be superior to the others.

Method of application

In all but one of the trials the fertilizers have been applied by hand to a circular area around each individual tree. Normally no fertilizer has been applied within 6 inches of the stem of the tree or farther than 3 feet from the tree.

A trial was begun in 1957 to compare foliar sprays containing urea with dry applications to the soil as described above. Half the foliar sprays were applied at a concentration of 2·5 per cent. weight/weight (w/w) in water, at rates to supply 11½, 23, or 46 lb. nitrogen per acre. This necessitated up to 400 gallons of spray per acre; thus, since as much as 25 per cent. of the spray ran off the leaves it had to be caught on tarpaulins to ensure that nutrient uptake through the roots was avoided. The second series of foliar sprays was applied with a low-volume machine ('Micron Meg' in 1957, 'Motoblo' in 1958), at the same rate of urea per acre in 20 gallons of liquid; the solution concentrations were therefore 12·5, 25·0, and 50·0 per cent. w/w of urea in the water. No serious leaf scorch was observed in 1957, but in 1958 the highest concentration led to considerable leaf damage similar to that described by Robinson [10], although no severe defoliation ensued. It was subsequently determined that the urea used in 1958 contained over 7·0 per cent. of biuret.

TABLE 6. *Method of Application*

Mean annual yields in cwt. clean coffee per acre. Responses % in parentheses

Method of fertilizer application	*Yield 1957–8*
Control	7·00
Means of treatments supplying 23 and 46 lb. nitrogen per acre as urea	
Dry application to the ground	8·55 (+22·1%) N.S.
High volume spray (200 and 400 g.p.a.)	8·51 (+21·6%) N.S.
Low volume spray (20 g.p.a.)	8·56 (+22·2%) N.S.

There was no significant difference between the treatments, but by analogy with other trials it seems likely that coffee yields may be raised by foliar applications of nitrogen in the form of urea.

The placement of nitrogen fertilizer in relation to mulch is dealt with in a later section.

Cattle Manure

Although the practice of applying cattle manure to coffee plantations has for many years claimed numerous adherents amongst experienced growers in Kenya, the results from field trials have not substantiated the immense advantages claimed for manure. Yield responses are not generally obtained except on eroded slopes, where the increases may be of economic importance.

Two forms of cattle manure have been tested. The first, which is known as 'Boma Manure', is derived from the enclosures in which nomadic herdsmen keep their stock by night. This material is most variable and may contain between 12 to 30 per cent. of water, from 45 to 75 per cent. of soil, and as little as 15 per cent. of the oven-dry matter may be organic [4]. The second form of cattle manure used in field trials is made on the Coffee Research Station from litter collected periodically from covered cattle sheds in which a herd of beef cattle is kept by night. This material is turned down a series of steps to form a compost similar to that known as farmyard manure in temperate farming regions. A typical analysis gave 40–50 per cent. of the total weight as water, and in the oven-dry matter 2·5 per cent. of nitrogen and 0·4 per cent. of phosphorus [11].

TABLE 7. *Yield Responses to the Application of Cattle Manure*

Mean annual yields in cwt. clean coffee per acre. Responses in parentheses

Trial	*Period*	*Number of seasons*	*Amounts of manure applied per tree annually (bushels)* 0	½	1	2
			(a) On deep fertile soil			
I	1947–58	12	6·56	6·51 (−0·07) N.S.	7·31 (+0·75)†	..
II	1950–8	9	7·71	..	..	8·27 (+0·56)*
IIIa	1948–51	4	5·25	5·37 (+0·12) N.S.	..	..
IIIb	1952–8	7	7·32	8·11 (+0·79)*	..	..
Weighted percentage response				+3·6%	+11·4%	+7·3%
			(b) On an eroded slope			
IVa	1950–3	4	3·29	4·66 (+1·37)*	..	..
IVb	1954–7	4	8·91	..	12·00 (+3·09)†	..

The annual application of up to 2 bushels of cattle manure per tree has increased the mean annual yield of coffee by a small amount only. In Trial IV, however, which is situated on an eroded soil, ½ bushel of manure per tree each year has raised the yield of coffee significantly in the years 1950–3; over the period 1954–7, when the level of cropping was distinctly higher and the rate of manuring doubled, there was a mean annual increase in yield of 3·09 cwt. per acre. It appears, therefore, that a considerable yield increase may be expected if cattle manure is applied to coffee grown on slopes which have lost their top soil as a result of many years' erosion, but on the level, deep, and fertile soils

representative of Kenya's best coffee-growing land, responses will be much smaller or negligible.

Cattle Manure and Nitrogen

It has been recognized for some time that there can be a negative interaction between cattle manure and nitrogen fertilizers [4, 5]. From yield results for the period 1950 to 1958, it appears that applications of nitrogen may eliminate the beneficial effect of cattle manure and the use of manure may reduce or eliminate the response to the fertilizer.

TABLE 8. *Cattle Manure and Nitrogen Fertilizers*

Mean annual yields in cwt. clean coffee per acre

Level fertile plantation

(*a*) *1950–6*

Annual application	*No nitrogen*	*92 lb. nitrogen/acre*	*Response to nitrogen*
No cattle manure	7·71	9·46	+1·75‡
Two bushels/tree	8·27	9·23	+0·96†
Response to cattle manure	+0·56*	−0·23 N.S.	

Level fertile plantation

(*b*) *1947–58*

Annual application	*No nitrogen*	*46 lb. nitrogen/acre*	*Response to nitrogen*
No cattle manure	6·56	7·86	+1·30‡
One bushel/tree	7·31	7·57	+0·26 N.S.
Response to cattle manure	+0·75†	−0·29 N.S.	

Eroded slope

(*c*) *1951–7*

Annual application[1]	*No Nitrogen*	*Ammonium*	*½ ammonium, ½ nitrate*	*Nitrate*	*Mean response to nitrogen*
No cattle manure	6·89	8·31	8·66	9·78	+2·03*
Cattle manure[2]	9·39	10·53	8·68	9·83	+0·29 N.S.
Response to cattle manure	+2·50†	+2·22†	+0·02 N.S.	+0·05 N.S.	

[1] Annual application { 1951–3: 23 lb. nitrogen per acre. 1954–7: 46 lb. nitrogen per acre.

[2] " " { 1951–3: ½ bushel/tree. 1954–7: 1 bushel/tree.

The results summarized in sections (*a*) and (*b*) of Table 8 clearly demonstrate this negative interaction where nitrogen fertilizer has been applied in the ammonium form (ammonium sulphate 1947–56, urea 1957–8). The results summarized in section (*c*) also show a negative

interaction between cattle manure and nitrogen applied in the nitrate form or applied half in the nitrate and half in the ammonium forms. However, where all the nitrogen has been applied in the ammonium form there is no evidence of such a negative interaction. This effect is contrary to the results given in sections (*a*) and (*b*) and no explanation can be given for this, although it may be related in some way to the fact that the trial is situated on a slope which has been seriously eroded.

Cattle Manure and Mulch

Just as the application of nitrogen to coffee treated with manure has reduced or annulled the effect of the manure so too has the laying of a grass mulch eliminated the yield response to cattle manure in a trial which has been recorded for the eight seasons 1950–7. Similar results have been reported from Tanganyika [5].

TABLE 9. *Cattle Manure and Mulch*

Mean annual yields in cwt. clean coffee per acre, 1950–7, on an eroded slope

Annual application	*No mulch*	*Grass mulch*	*Response to mulch*
No cattle manure	6·10	8·77	+2·67‡
Cattle manure[1]	8·33	8·81	+0·48 N.S.
Response to cattle manure . . .	+2·23†	+0·04 N.S.	

[1] Annual application: 1950–3, ½ bushel/tree; 1954–7, 1 bushel/tree.

The mulch treatment in this trial has been a 7-foot-wide strip of cut Napier grass (*Pennisetum purpureum* K. Schum.) laid to give a settled depth of 4 inches. One of the principal objects of this trial was to discover whether cattle manure might be more effective under Kenya conditions of periodic intense drought if it were protected from the sun by a layer of organic matter rather than merely being lightly forked in around each coffee tree. The yields given in Table 9 show that where either mulch or cattle manure was applied to the coffee mean annual responses in excess of 2 cwt. of clean coffee per acre were recorded, but where the two were applied together the yield increase was no greater than when either was applied separately. Thus the two factors have not been additive but there has been between them no significant negative interaction.

Mulch

The value of grass mulches to coffee grown in the drier parts of Kenya (mean annual rainfall less than 40 inches) has frequently been confirmed since Pereira and Jones reviewed cultural practices to maintain the fertility of dry coffee soils [3].

Undoubtedly the principal benefit from mulching is associated with its effect on the acceptance of rainfall by the soil and the control of soil and water loss by erosion. However, since the application of 7-foot-wide

TABLE 10. *Yield Responses to the Application of Grass Mulch*

Mean annual yields in cwt. clean coffee per acre. Responses % in parentheses

Trial period		*Number of seasons*	*No mulch*	*Alternate inter-rows*	*In all tree rows*	*In all inter-rows*	
Time of application:				*March*[1]	*March*[1]	*March*[1]	*July*[2]
				(a) On deep fertile soil			
I	1954–8	5	7·23	8·88 (+22·8%)*	..	..	..
II	1954–8	5	10·16	11·61 (+14·3)%)†	12·13 (+19·4%)‡	11·50 (+13·2%)*	..
Weighted percentage response				+17·8%	+19·4%	+13·2%	..
				(b) On an eroded slope			
III	1950–8	9	5·93	7·86 (+32·5%)*	..	8·71 (+46·9%)‡	9·25 (+56·0%)‡

[1] Pre-Long Rains. [2] Post-Long Rains.

mulch strips in alternate inter-rows of coffee planted at 10 × 10 feet supplies about 10 tons of dry matter per acre it is evident that this practice is also a form of organic manuring by which very large amounts of nutrients are applied to each acre mulched. An example of a Napier grass mulch analysis in terms of plant nutrients applied to an acre of coffee following complete breakdown has been estimated by Robinson [17], viz.:

Plant nutrient	N	P	K	Ca	Mg
lb. per acre per annum . .	109·1	18·7	1,196·6	17·9	29·1

Mulch, Potassium, and Magnesium

Robinson and Chenery have recently described the magnesium deficiency syndrome in both Robusta and Arabica coffees and have demonstrated the indirect rôle played by mulching practices in respect of the tendency this cultural treatment has towards inducing a magnesium imbalance in coffee. The supply of excess potassium which results from the breakdown of organic mulches was shown to be a primary cause particularly where the soil contains an adequate naturally available supply of this cation [9, 13]. Recent comparative soil analyses of plantation samples tend to confirm that much of the Kenya coffee acreage is situated on soils containing adequate quantities of exchangeable potassium. A large proportion of these soils is derived from parent material of volcanic origin. In unmulched coffee under heavy shade a similar condition develops following the decomposition of fallen leaf of the shade trees (e.g. *Grevillea robusta*).

Previous fertilizer studies carried out in Kenya and quoted by Pereira and Jones [4] confirmed a lack of response in mature coffee to potassium

fertilizers. For this reason and because mulching is now very generally carried out on coffee plantations, further field studies with potassium fertilizers have not been pursued.

Investigations are now proceeding to control the induced magnesium imbalance in the coffee and to prevent the condition from becoming increasingly severe.

Napier grass is the most generally grown mulch grass in the industry because of the large yield of dry matter produced per acre under a wide range of climatic and soil conditions. This grass is a luxury consumer of potassium, and analytical values for K in the dry matter of mature grass cut for mulching may be, and often are, as high as 4·0 to 5·5 per cent. Thus, investigation of the mulching deficiency of other indigenous grasses which have lower potassium contents is also being undertaken, e.g., *Panicum coloratum* (*sensulatum*), *Cymbopogon afronardus*, *C. validus*, and *Hyparrhenia* spp. This investigation covers such things as comparative yield, efficiency of ground cover, and persistence of these grasses, and comprises one part of the current study of magnesium nutrition in mulched coffee.

Mulch and Nitrogen

Recent work of Birch [14] and Robinson [15] has drawn attention to the importance of the alternation of soil drying and wetting cycles on the release of natural nitrogen from soil organic matter. Since it has also been shown that mulch reduces the severity with which the top soil dries out, an interaction between mulch and nitrogen fertilizers might be expected [16]. Results from the two trials on the Coffee Research Station which were designed to study this interaction are given in Table 11.

It is clear that no negative interaction has been found between ammonium nitrogen and mulch, but where all or half the nitrogen was in the nitrate form there was no significant response to the mulch treatments.

An investigation was commenced in 1954 to study the yield response to a nitrogen fertilizer scattered over a 4-inch layer of mulch or distributed over the bare soil.

The results so far suggest that the lower rate of fertilizer dressing (69 lb. nitrogen per acre per annum) has been more effective where it was applied to the bare soil but, at the higher rate, the placing of the fertilizer has had little influence on the ultimate yields recorded.

Plant Nutrients Removed in the Coffee Crop

No presentation of crop fertilizer requirements and responses would be complete without some indication of the plant nutrients removed in the crop at harvest time. Such information assists in placing the necessary emphasis for evaluating the quantitative requirement of plant nutrients in their order of importance. This may be of value when endeavouring to correlate the results of soil and foliar analysis with crop yield. In this respect, however, it is important to bear in mind that peak

TABLE 11. *The Interaction of Mulch and Nitrogen*

Mean annual yields in cwt. clean coffee per acre

Trial period	*Number of seasons*	*Annual dressing of nitrogen per acre*	*No grass mulch*	*Grass mulch*	*Response to mulch*
		(a) On deep fertile soil			
1954–8	5	Nil	9·47	10·81	+1·34*
		138 lb. (ammonium)	10·82	12·16	+1·34*
		Response to nitrogen	+1·35*	+1·35*	..
		(b) On an eroded slope			
1951–8	8	Nil	6·60	9·57	+2·97‡
		Ammonium[1]	7·72	10·50	+2·78‡
		½ Ammonium,[1] ½ Nitrate	8·12	9·46	+1·34 N.S.
		Nitrate[1]	9·12	9·67	+0·55 N.S.
		Response to ammonium form	+1·12 N.S.	+0·93 N.S.	
		Response to nitrate form	+2·52‡	+0·10 N.S.	

[1] 1951–3: 23 lb. nitrogen; 1954–8: 46 lb. nitrogen.

TABLE 12. *The Placement of Nitrogen Fertilizer*

Mean annual yield increases over the control yield of 9·47 cwt. clean coffee per acre, 1954–8

Annual rate of nitrogen per acre:	*to the bare soil*	*over the mulch*
69 lb.	+2·95‡	+1·73*
138 lb.	+2·39†	+2·99‡
L.S.D. = 1·65*	2·22†	2·93‡

requirements for a specific nutrient may occur at a certain physiological stage in the production of crop before harvest time. The amount of nutrient available to the tree from a soil at a specific time may be such as to impair the tree's efficiency and hence reduce its production.

A typical set of analytical values for some of the major plant nutrients contained in ripe coffee cherry is given in Table 13. Red-ripe cherries were collected at random from within a uniform area of mature mulched coffee which was carrying a heavy crop.

A crop of 60 cwt. of cherry per acre is equal to about 10 cwt. of clean green coffee. This is a good average yield within the climatic zone represented by the Coffee Research Station. Sub-samples of the cherry were taken and dissected into the three major component parts, to illustrate what portion of the total nutrients removed from the field

TABLE 13. *Analytical Data for Coffee Cherry*

Sample	*Water* %	*Dry matter lb.*	*Percentage in dry matter*				
			N	P	K	Ca	Mg
Whole cherry	69·7	2,036·0	1·180 (24·0)	0·1105 (2·20)	1·93 (39·2)	0·20 (4·0)	0·12 (2·44)
Skin . .	80·8	559·8	1·118 (6·2)	0·1104 (0·60)	3·28 (18·4)	0·33 (1·8)	0·09 (0·50)
Parchment and mucilage	74·0	409·2	0·461 (1·8)	0·0318 (0·14)	0·35 (1·4)	0·13 (0·6)	0·05 (2·20)
Bean . .	52·0	1,064·8	1·460 (15·5)	0·1317 (1·40)	1·45 (15·4)	0·14 (1·6)	0·19 (2·02)

Note. Figures for dry matter and those in parentheses are calculated values for pounds in 60 cwt. of cherry.

actually leave the plantation. Thus, in Kenya the skin is retained on the plantation, the mucilage is lost during the fermentation processes, and the bean plus parchment is sold off the plantation. The plantation therefore retains approximately a quarter of the nitrogen and phosphorus, a little less than half the potassium and calcium, and less than a quarter of the magnesium. It is noticeable that the total quantity of phosphorus removed in the cherry is small, and reference to the Napier grass mulch analysis figures (p. 345) illustrates the substantial annual credit balance of phosphorus and more particularly of potassium that is maintained.

Micronutrients

Exploratory field trials have been laid down with several different micronutrients in the chelated form, e.g. zinc, iron, copper, and manganese, but it is too early yet to draw any conclusions. Past studies have been concentrated largely on the recognition and diagnosis of visual deficiency or imbalance symptoms in the field [17] and correlation of foliar diagnosis with correction of the field condition [18].

Mild symptoms of iron and zinc deficiency, or imbalance, can be found in many Kenya coffee areas at certain times of the year, usually on young suckers or tertiary growth made under sub-optimal or adverse growing conditions. The incidence of these visual symptoms is not high during the major growth flush periods, when they disappear from existing leaves and are not visible on new growth. It seems likely that a shortage of available moisture plays an important part in this relationship. Work is being undertaken to evaluate the economic aspects of controlling these conditions in the field.

Quality

During the course of the trials reported in this paper samples have been collected regularly to determine the quality of the coffee.

As a measure of the physical character of the coffee an 'A' (6·75 mm. diameter round holes) screen is used to grade the beans by size. While

there have not yet been any indications of fertilizer or manure dressings affecting bean dimensions, mulch has increased the percentage of beans retained by an 'A' screen.

TABLE 14. *Percentage by Weight of Coffee retained by an 'A' Screen*

Mean figures for the eight crops, 1951–8

Control	3·92%	
Alternate inter-row mulch—March	4·19%	N.S.
All inter-row mulch—March	47·1%†	
All inter-row mulch—July	46·2%†	

Samples of coffee from these trials have been submitted for assessment by the Liquorer of the Coffee Board of Kenya on many occasions, but none of the cultural treatments has affected consistently the reports made on the raw or roasted beans or liquor of the samples. In the liquor reports on the 1958 crop there were indications that magnesium fertilizer dressings had improved the coffee quality, although the difference did not attain statistical significance.

Discussion

The absence of any yield response to two forms of phosphorus fertilizer confirms the finding made five years before, although the subsidiary evidence differs. Whereas Pereira and Jones [4] found some indication of uptake, Table 2 reveals no significant differences in foliar phosphorus content. An examination of the status of available soil phosphorus in the trial shows an enhanced level where cattle manure and phosphates were applied together, due presumably to the action of organic matter in impeding inorganic fixation. Coupled with the previous results there is now extensive evidence to support a firm conclusion that the amount of phosphorus needed by the mature tree can be obtained from natural sources provided by the breakdown of plant residues. Table 13 illustrates the low level of phosphorus removal in a good average crop. Cereals, however, respond to phosphorus fertilizer dressings on this and similar coffee soils to a degree which suggests that the young tree will benefit from an augmented supply while its root range is limited; hence dressings of phosphate are recommended for transplants although direct evidence in favour of this treatment is lacking.

It should be possible to construct a response curve from the range of nitrogen levels tested, but no clear picture of the optimum nitrogen level, in the ammonium form, is evident from Table 3. The yield data up to 1955 pointed to an optimum in the region of 92 lb. of nitrogen per acre. The subsequent evidence now suggests that nitrogen at the rate of 46 lb. per acre gives the most economic response. It must be recognized that during the course of these trials the cultural management and rainfall improved, with a consequent increase in the average level of yield. A further factor to be taken into account in the evaluation of these results is the abnormal defoliation which has occurred in all the trials during the last three years, caused by Leaf Rust (*Hemileia vastatrix*)

and Leafminer (*Leucoptera* spp.) attacks. Much of the leaf was lost between the Long Rains and Short Rains, at a time when the beneficial effects of fertilizer nitrogen are greatest. These facts may be related to the absence of a graduated response. Where supplementary irrigation is practised in accord with the principles expounded by Pereira [19], the nitrogen demand is likely to be greater, to rectify the losses by leaching and a reduced level of nitrogen mineralization in wetter soils [14, 15, 20], and to satisfy the needs of more sustained growth and heavier crops [5] (also R. W. Rayner, unpublished report 1954). Factual evidence on this aspect is not yet available, however, and no inference may be drawn from a study of the rainfall variation and its relation to nitrogen response in these trials. It has been shown in soil studies [21] that a given quantity of nitrogen applied in the form of sodium nitrate raised the soil nitrate-nitrogen to a higher level and for a longer period than did the same quantity of nitrogen applied as ammonium sulphate or urea. This may account for the greater yield response to sodium nitrate appearing in Table 4; the possible direct effect of the sodium on crop yield is worthy of consideration, and studies have been initiated to investigate this. The detrimental effect of ammonium sulphate dressings in lowering soil pH has been described [6], but since the superiority of sodium nitrate was evident at an early stage in the trials the difference cannot be ascribed solely to this effect.

In studying the time of application due attention has been paid to variation in growth and the supply of natural soil nitrogen throughout the year. The rate of vegetative growth is normally greatest during the Long Rains (late March to early June) whereas the natural nitrogen in the region of the surface root mat is at a low level from late April until the top soil begins to dry out. Supplementary nitrogen might be expected to exert most effect on growth if timed to counteract this deficit. In respect of the first half of the year this hypothesis has been proved correct [8]. Nevertheless, a parallel but less extreme situation obtains during the Short Rains. As shown in Table 5 no yield differences due to timing have arisen, so that it may be inferred that the season at which additional growth is encouraged by supplementing the nitrogen supply to the tree is immaterial with regard to crop yield. The influence of the crop on vegetative growth may account for this, namely, it has been observed that the maturing crop has some inhibiting effect on growth during May and June, whereas a release from crop strain at the end of the year is usually followed by a flush of leaf growth, providing soil moisture is not limiting at this time. Hence additional nitrogen may be utilized more for vegetative growth after the crop is removed than in May and June.

Responses to cattle manure since 1953 have largely confirmed those observed previously, except that heavier rates of manure have increased yield slightly on fertile soil. Much higher yields and a better rainfall distribution have prevailed since 1953 and in this respect there is a marked difference between the two periods which may account for a response during the second five years, although the cumulative effect of manure on the soil cannot be discounted.

A greater response to mulching than to cattle manure has been recorded, however, and, on eroded slopes at least, there is the additional value of mulch in preventing further erosion. This alone constitutes adequate grounds for preferring mulch to cattle manure on eroded slopes and there is no advantage in applying both (Table 9). Whilst there seems no basis for the principle of protecting manure with a mulch cover, the quantities of nutrient and organic matter in the latter so much exceed those in the manure (at the rates tested) that an additive effect could not be expected. Notwithstanding this conclusion, cattle manure in the planting hole and a layer of grass mulch around the transplanted seedling is still advisable: where there is a limited volume of feeding roots, moisture and nutrients readily available to the plant are likely to be essential, mulch and manure respectively providing these two needs.

The interactions of nitrogen with manure or mulch are curiously conflicting in some of their aspects. In the nitrate form there has been no additive effect with either manure or mulch, although nitrate nitrogen alone has been superior to the ammonium form (N.B. nitrate nitrogen has not been tested on fertile soil). The ammonium forms have produced additive trends with either manure or mulch on eroded soil, but with mulch only on a fertile soil. A possible explanation for the lack of an additive effect of manure and ammonium nitrogen may lie in the smaller responses which manure alone produces on a fertile soil (Table 7*a*); whereas on an eroded soil a valuable response is obtained from the addition of organic matter as well as from the nitrogen fertilizer. A comparison of the relative interaction effects between sections (*b*) and (*c*) of Table 8 supports this explanation. Examination of Table 11 (*b*) suggests that the response to mulch with ammonium nitrogen (+2·78 cwt./acre) is probably related to the small response obtained from the fertilizer alone (+1·12 cwt./acre). On the other hand, the response to sodium nitrate alone was much greater (+2·52 cwt./acre) and has not been raised significantly by the addition of mulch (+0·55 cwt./acre). Studies conducted adjacent to this trial [21] show that sodium nitrate results in significantly higher soil nitrate values in bare soil than in mulched soil.

While investigations are proceeding on the correction of magnesium imbalance the Coffee Industry is being advised to remedy visual symptoms of the syndrome by dressings of magnesium fertilizer and inclusion of Epsom salts or anhydrous magnesium sulphate in foliar sprays.

The visible patterns of micronutrient deficiencies are recognized in the field both by diagnosis in Kenya and by comparison with established information from other coffee-growing areas, notably Costa Rica and the Kivu area of the Belgian Congo. The commonest conditions are those attributed to iron and zinc deficiency. Observations suggest that such conditions in Kenya coffee areas are more usually of a temporary and seasonal nature and investigations are now being undertaken to define the importance of control in terms of crop yield.

As Kenya is recognized as a producer of high-quality coffee an important feature of these trials has been the effects on quality. None of the

increases in the mean annual yields reported in the foregoing has been associated with any loss of quality: improved cultural practices have increased crop yields and tended to improve quality at the same time.

General advice to the grower which may be derived from these investigations is as follows:

Mulch should be laid in alternate inter-rows before either Rains; where mulch is not available apply cattle manure on eroded slopes at one bushel per tree annually. Where neither can be employed, apply a nitrate fertilizer at 46 lb. of nitrogen per acre, split into two dressings in the Long Rains or at 23 lb. per acre in each Rains. Where mulch or cattle manure has been distributed use an ammonium form of nitrogen instead of the nitrate form.

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